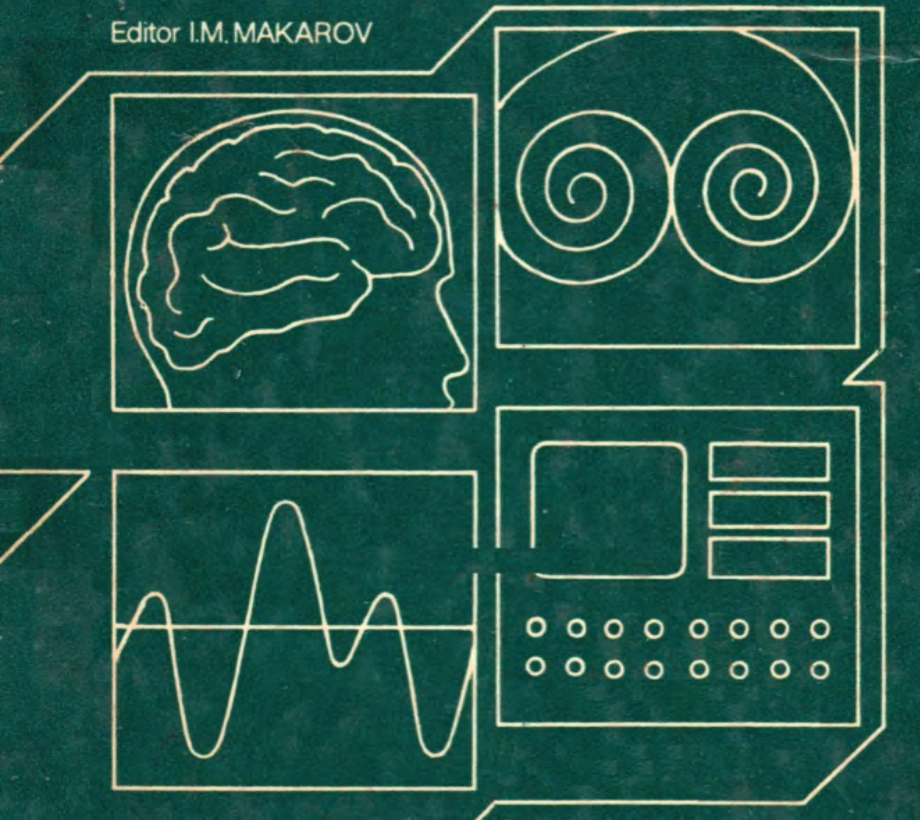
Cybernetics of Living Matter: Nature, Man, Information

Editor I.M. MAKAROV



Cybernetics of Living Matter

Кибернетика
живого

Под редакцией чл.-корр. АН СССР
И. М. Макарова

Составитель — В. Д. Пекелис

Издательство «Мир»
Москва

Cybernetics of Living Matter: Nature, Man, Information

Editor

I. M. MAKAROV,

Corresponding Member
of the USSR Academy of
Sciences

Compiled by V. D. Pekelis

Translated from the Russian
by V. I. Kisin

MIR PUBLISHERS MOSCOW

First published 1987

На английском языке

Printed in the Union of Soviet Socialist Republics

Contents

Preface

The breathtaking discoveries of today's biology not only revolutionize our view of the living matter but also make a profound impact on medicine, agriculture, and a number of manufacturing industries. Had the ideas and methods of cybernetics not been taken over by the biological theory and its applications, these discoveries would, however, be inconceivable.

Control science, theory of large-scale systems, information theory, studies of data transmission systems and communication channels in the living matter coupled with the ideas and techniques coming from chemistry, physics, and mathematics shape the biological science of today. All of its numerous "narrow", "specialized", or "traditional" fields have experienced a profound impact of cybernetics; its heuristic fruitfulness, now indispensable for biology, is obvious in all of them.

Extensive utilization of experimental methods, simulation studies, and systems analysis promoted biology to the rank of exact science. Some people have probably forgotten that biology used to be a descriptive discipline.

The successes scored by this science are impressive and widely acclaimed. For illustration, I will take up my own line of research, physico-chemical biology.

Soviet scientists have significantly contributed to unraveling the basic mechanisms of storage and expression of genetic information, to discovering the laws of regulation

and energy supply in a living cell, and to studying the structure and chemical synthesis of substances.

Genetic engineering which came into existence about ten years ago has been fruitfully developing in the USSR. This new science makes it possible to change in a purposeful way the machinery of inheritance, to "design the living matter". Biotechnological processes are utilized in the manufacture of medical drugs, foodstuffs, and fodder. A major task for our science today is to expand and deepen basic research and to make its findings work in practical fields.

The humanitarian nature of today's biology should by no means be overlooked. It is essential for science as an entity and especially for genetics and psychophysiology and for research on the structure and functioning of the brain.

Narrowly specialized researchers who, by force of tradition, explore the unknown by advancing along their cherished "rut", usually find themselves in a cul-de-sac. They may obviate this predicament when they study something less complicated but in trying to solve the mysteries of Man the scientist should deliver the attack in the most interdisciplinary fashion. For this reason the "cybernetics of the living matter" cannot be treated apart from various aspects of its application to studies of man.

Every scientist is aware of the pressing need in comprehensive studies of man. Even if a far cry from approaching the answers, every step forward must be thoroughly reported.

The vital importance of every research project in this field, particularly those of Soviet scientists, cannot be overemphasized.

Man will remain a mystery unless certain basic problems are resolved, problems of such magnitude that scientists of the whole world pull their efforts together to attack them. The reader will recall that human thought developed most

successfully whenever the new knowledge was jointly shared and comprehended.

This collection of papers addresses a wide range of readers. The title of the book is hardly surprising. The importance of cybernetics approaches to biology has been widely appreciated in the last decades and found overwhelmingly fruitful. I believe that this book reporting the cybernetics-aided findings of Soviet researchers in diverse biological fields will give the reader a wider view of this science.

Academician Yu. A. Ovchinnikov,
Vice-President of the USSR Academy of Sciences

Note from the Compiler

This collection of papers, as the reader will see from its title, "Cybernetics of Living Matter: Nature, Man, Information", dwells upon the fields of biological cybernetics and data processing in physiological systems. This choice is explained in the Preface and in the opening article written by a leading Soviet authority in biology Academician Yu. A. Ovchinnikov, Vice-President of the USSR Academy of Sciences: "The scope of interests and problems in today's biology is extremely wide: from elementary processes in a living cell to the development of the entire organism, to its interaction with other organisms and the environment in the ecological system. Today's biology is rapidly evolving branch of science, rich in exciting problems and prospects, commanding an army of enthusiasts, and armed with the most advanced techniques and equipment. Biology holds key positions in solving the global problems mankind confronts, be it the battle against fatal disease, the food crisis, or the pollution of the environment".

It was long ago that cybernetics "took note" of biology while mathematical exploration of biology has a still longer history. Enhanced by the intersection of various fields of knowledge, penetration of mathematics into biology was especially vigorous during the last two or three decades.

For a long time biology has been influenced by new ideas of physics and chemistry. The reader will recall the once sensational "What is Life? The Physical Aspect of the Liv-

ing Cell" by E. Schrödinger, "The Kinetic Fundamentals of Molecular Biology" by a group of scientists, and "Molecules and Life" by M. V. Volkenshtein, Corresponding Member of the USSR Academy of Sciences, one of the contributors to this collection, to understand that in treating various issues in biophysics, biochemistry, and molecular biology problems arise which are akin to those in theoretical physics and chemistry. Application of physical and chemical findings to biological research naturally results in a mathematical way of thinking and in the use of techniques borrowed from informatics and cybernetics. Today biological studies are unthinkable without mathematical tools, control theory, and information theoretic concepts.

It is a remarkable fact that biology has been not only a field of application for cybernetics where the potential of new theories was tested but also an aid in making new discoveries. Biology has proved very helpful in artificial intelligence, pattern recognition, robotics, and other fields of research. The complexity of such phenomena as the functioning of the brain, interactions in biological communities, adaptability, reproducibility, survival of living organisms, and their high reliability called for more sophisticated mathematical models and new control procedures. Thus search for mathematical modeling of reproduction processes culminated in the theory of self-reproducing automata.

A complete list of cybernetic applications to biology would be impressive by its mere size. We will name just a few: studies of principles underlying the control of physiological processes in an organism as an entity; analysis of control and regulation mechanisms in physiological systems such as blood circulation, respiration, and exchange of matter and energy; systematic representation and mathematical modeling of evolutionary processes; studies of control and data processing mechanisms in embryogenesis and growth

of the organism; studies of reliability in living nature; various levels of studying the oscillatory process as a major principle embodied in the organization of biological systems; analysis of the behaviour of living beings in various environments; unraveling the mechanisms of the brain functioning; and development and manufacture of biotechnical assemblies which would act as live organs.

Cybernetically, the most challenging lines of research are the control mechanisms and data processing in living beings and possible applications of information-theoretic methods to studying the functioning of human sensory organs, nervous system, and behaviour.

Of course, a small book cannot cover all these aspects. The reader will find in it several enlightening articles on controversial issues. Some of the articles provide overviews of their fields while others describe specific research projects.

In addition to a survey of general trends in physico-chemical biology made by Academician Yu. A. Ovchinnikov, this collection includes an article reporting an applied study, "Autowaves: an interdisciplinary finding". In this article a merger of physico-chemical and informatics approaches to biological phenomena is shown to give rise to a new line of research which results in the discovery of fascinating world.

The new classical research of A. A. Lyapunov, Corresponding Member of the USSR Academy of Sciences, on a cybernetic approach to theoretical biology is followed up in the collection by Yu. M. Svirezhev's article "Control sciences and the harvest" in which he tried to demonstrate the use of "non-conventional" tools in agriculture which is viewed as an inhomogeneous complex system consisting of energetic, economic, ecological, and informational components. He proposes a technique for determining the conditions under which the system will operate in an optimal way.

The much-discussed and ever-relevant issue, the evolutionary theory, is viewed from different standpoints by N. V. Timofeev-Resovsky in his "Genetics, evolution, and theoretical biology" and M. V. Volkenshtein in his "Information theory and evolution". The former shows that a better understanding of the evolution largely depends on the development of a general theory of biology and the latter concentrates on the value of information in biological structures in the course of evolution. Both authors analyze a variety of complex scientific data on this very important issue.

Academician B. S. Sokolov argues in his review "A half century of thinking in biology" of A. A. Lyubishchev's book "On ways to systematize the evolution of organisms" that the discouraging fact in some biological fields such as the evolutionary theory is excess, rather than shortage, of various ideas. Indeed, biology abounds in various descriptions, observations, experimental results, and models. This flow of information cannot be handled by the available processing tools. The overriding need of biology is now to evaluate the "product" supplied to the information "market". For this reason, according to B. S. Sokolov, criticism has a major role to play. This criticism "manifests itself in different ways and on different levels, from the procedures of specific research projects to philosophic interpretation of scientific activity as a whole".

In this contexts the parts of this collection "Science and new information" and "New horizons in cognition" should be approached. The articles under these headings range from reports of the concrete findings to philosophical and methodological approaches to some issues. The former kind is represented by the article "Man's magnetic fields" by V. L. Vvedensky and V. I. Ozhogin who demonstrate how the measurements made by super-sensitive magnetic instru-

ments facilitate medical diagnostics and the studies of human brain.

Yu. V. Gulyaev and E. E. Godik, the authors of the article "The physical fields of biological objects", report a series of profound investigations accomplished by most advanced experimental methods, using precise physical instruments interfaced with computers. This work is being carried out now at the Institute of Radio Engineering and Electronics of the USSR Academy of Sciences.

The complexity of topics discussed in this collection made it imperative to include philosophical-and-methodoligical articles. These are grouped under a general heading "Science and New Information". The first article there, by A. M. Migdal, full member of the USSR Academy of Sciences, and Ye. V. Netesova, "Road to truth (on the scientific method of cognition)" discusses the differences between scientific and unscientific treatment of the phenomena in the world around us, between what is true and what is not in science.

D. I. Dubrovsky ("Criteria of existence and conflicting situations in science") analyzes from the materialistic point of view the criteria of existence and inexistence. In terms of knowledge and ignorance (we know that we know; we know that we do not know; we do not know that we do not know; which reminds of a biological catchword, from false knowledge to true ignorance) the author tries to analyze philosophically what is possible and what is not in science as far as informatics and cybernetics are concerned.

B. V. Biryukov ("On new knowledge in biological studies") defines scientific, pre-scientific, and unscientific sensations.

The scientific process is analyzed by S. E. Shnol. His article "The dynamics of new truths in biological sciences" unravels the causes for delayed recognition of some discoveries.

With all their variety the articles in this collection pursue

the theme of the functioning of living matter and information, or data processing and cybernetic aspects of biology. It is because many areas remain unexplored and problems unresolved that the truth and falsity in science and sensational findings had to be discussed.

As biology employs data-processing methods on an ever increasing scale, new results are obtained and, which is equally important, well-known facts are viewed from new standpoints. The ever-growing cooperation of cybernetics and biology facilitates the development of non-conventional approaches. Numerous new mathematical systems serve purely biological purposes.

The application of informatics to living nature has yielded certain negative results valuable in the sense that certain things were found impossible. Thus the functioning of the whole cannot be studied in a number of cases until "full" knowledge of its components is available. The super-complex living systems incorporate two-way links which cannot be found unless the functioning of the components has been explored both "horizontally" and "vertically".

The data processing approach is very promising; thus far it has helped determine new aspects in the functioning of complex living systems.

In the articles of this collection man is viewed as a complex system. In studying man, every discipline should maintain its specific features and at the same time recognize the interaction of various fields of knowledge and the complexities of comprehensive studies. The awareness of this aspect is obvious in all articles of the collection and helps the authors either to answer questions or to pose new questions.

Karl Marx foresaw comprehensive studies of man. He said: "Natural science will in time incorporate into itself the science of man, just as the science of man will incorporate into itself natural science: these will be one science".

Indeed, now man is being studied by philosophers and sociologists, specialists in ethics and pedagogy, physiologists and medical scientists, and many other scientists.

Quite naturally, all the aspects of these studies could not be treated in the framework of several Parts of this collection. The authors, however, tried to raise most interesting questions.

In the context of the technological revolution and its consequences man becomes the strategic goal of cognition. This is what the article "On systemic, integral nature of man" is about. Its author V. G. Afanasyev, full member of the USSR Academy of Sciences, is one of the founders and a most active protagonist of systems research in the Soviet Union. He has made an important contribution to research on the philosophical dimension of the systemic character of nature and society.

Man is said in his article to be not only the "centre", or "focal point" of a social system but also a biological being which is a mobile self-controlled integral system, a concentration not only of social relationships but also of the objective world in the variety of its manifestations. In fact, man organically combines all laws of the universe, mechanical, physical, chemical, biological, and social, the latter being dominant and system-generating.

Marx also said that man is a part of nature. But Marx and Engels provided a profound understanding of man's dependence on nature and the social significance of that dependence. Marx wrote of human nature as a totality of his life powers. This essential formulation is in no way in conflict with another Marx's formula, that man is a totality of all social relationships.

A sound informatics-and-biological approach organically combines physico-chemical tools, a biological statement of the problem, and cybernetic ideas. In this way a new step

is made towards understanding the phenomenon of life in the cognition of man and adds to the hierarchy of models which provide an insight into the super-complex systems of intelligent living beings.

The article "Transition to constructing living systems" is worthy of special attention. Its author, A. A. Baev, full member of the USSR Academy of Sciences, is active in molecular biology and genetic engineering. He demonstrates that with the advent of genetic engineering the experimental biology entered a new stage of development which can be regarded as very promising. The author comes to a conclusion that the concepts of information, coding, control, and feedback and of the entire control engineering methodology have enhanced the treatment of numerous conventional biological issues and, which seems especially significant, have been instrumental in restating some issues (such as decoding of the genetic information), and in resolving complex problems in genetic engineering.

Although its achievements are still modest, the promise of genetic engineering in the designing of living beings is such, notes Baev, that one has to restrain one's imagination in forecasting the future successes.

The Part "Brain and Intelligence" in this collection includes a slightly abridged version of a widely-known article by P. K. Anokhin, full member of the USSR Academy of Sciences, a Lenin Prize laureate, "Natural intelligence versus artificial intelligence: the philosophical view" which still remains relevant. The author tries to show the limits of modeling the mind and the potential of developing artificial intelligence.

Speaking of the cognition of the brain, its functional mechanisms, and molecular nature, Anokhin subtly leads the reader to a conclusion that the techniques of brain activities should be employed in designing artificial intelli-

gence. The highlight of the article is in that the evolution of neurophysiological mechanisms suggests the systemic nature of their formation aimed at predictive reflection of the events in the environment. In characterizing the "functional systems", Anokhin indicates the difficulties inherent in a direct application of neurophysiological findings to control hardware.

Reliability of the brain is the subject of A. B. Kogan's article. An attractive feature of his article is the stringent boundary of his research.

Another Part of the collection, "Novel Aspects", reports interesting results in studies of biorhythms by V. N. Reushkin and of the biology of sleep by V. S. Rotenberg. In his article "Diurnal rhythms and adaptation", Reushkin reports that studies of nearly-diurnal rhythms have experimentally shown that if an exogenic signal which invokes an anxiety response (in H. Selye's terminology) is repeated daily, then an expectation response is generated. This response, the author believes, improves the stability of the organism to a similar signal and improves its adaptability. Analysis of nearly-diurnal rhythms gives a clue to an individual's health and makes it possible to predict illness.

Sleep is known to be widely interpreted as a factor enhancing adaptation to the environment. A new explanation of this adaptive significance of sleep is offered in the article "Searching activity, sleep and stability of the organism" written by V. S. Rotenberg. His own research, V. V. Arshavsky's experimentation, and analysis of the extensive literature on the subject have led Rotenberg to a conclusion that a kind of information-seeking activity takes place in one's sleep. This activity offsets the biologically harmful effects of abandoning the search for necessary solutions in wakefulness. This mechanism may be regarded as a kind of feedback model which connects in one loop the psycholog-

ical state of a personality, the physiological parameters, and the biochemical processes in the organism.

The same Part of the collection includes an article by V. I. Klimova "On man's third state". The organism's state when one is "neither healthy nor sick" is viewed in the light of data processing principles applied to medicine and biology. An increasing amount of attention is given to "the third state" because, unfortunately, too many people stay in it for too long.

Several articles discuss psychological fields such as the psychology of cognition, subconsciousness and superconsciousness, and some problems of engineering psychology. Cybernetic techniques make it possible to study psychological processes in conjunction with physical, biological, and social phenomena, to find some common features, and to demonstrate the specifics of psychology itself.

Cybernetic tools have a major role to play in psychological research. New industrial processes and automatic systems make quite sophisticated requirements to man. Psychology has therefore to rely ever more heavily on mathematical modeling and computers. Although psychological processes cannot be downgraded to physical and physiological ones, this new line of research, especially in experimentation, can boast of significant breakthroughs.

The cognition psychology has made important conclusions from the study of mentality and behavioural studies in general psychology and kindred disciplines and then started theoretical and experimental analysis of mental processes. This new line of research deals with the construction of the perceived pattern, the forms and structure of human knowledge, and the relationship of automatic and consciously controlled cognitive processes. Numerous models of perception, attention, memory, and thinking processes are now available. On the other hand, certain difficulties arise

from overestimation of the similarity between the functional structure of cognitive processes in man and the data processing structure in computers.

In his article B. M. Velichkovsky analyzes the history, problems, and promise of the cognitive psychology; he believes that the approaches which neglect the complex, systemic qualities of the mind have an essentially limited application.

The complexity of the sphere of the unconscious in human mind is the subject of the article "Subconsciousness and superconsciousness" by P. V. Simonov, Corresponding Member of the USSR Academy of Sciences. The latest findings of basic research suggest that there are several levels of consciousness, in particular, of superconsciousness which follows its own rules; that man is not fully aware of the needs which dictate his actions; and that consciousness, subconsciousness, and superconsciousness interact in a certain way. The basic conclusion of the article is that a materialistic solution to the most urgent problems in science of man cannot be obtained unless the most important functions of unconsciousness processes are recognized and these processes are classified into sub- and superconscious ones which are essentially different.

"The principle of active operator in engineering psychology" is described by B. F. Lomov, Corresponding Member of the USSR Academy of Sciences, who convincingly shows that the operator in a man-machine system cannot necessarily be described as a mere communication channel. He illustrates his point with reference to a "pilot-aircraft" system which is very sensitive to the weak points in data exchange between its components.

The final Part of the book is "The Organism and Age". This topic has never been more relevant. The Earth population is known to "age". In 1950 a mere 200 million people,

or 7.7 per cent of the world population, were older than 60. In 25 years there were 350 million of them, or 8.5 per cent. Every day 200,000 persons reach this age. The twentieth century is quite justly referred to as the age of increasingly long life.

Demographers say that very soon the average life span will grow to 85 or even 90 years. The UN forecast predicts this too. Within the time span of 75 years, from 1950 to 2025, the number of people over 60 is expected to grow five-fold and of people over 80, seven-fold. Consequently, whereas in 1950 only one of every twelve people was over 60, in 2025 this will be true of one of every seven inhabitants of the planet.

In the Soviet Union, where the average life span is very high, over 70 years, about three million people were recently reported to be older than 80, of which 300,000 older than 90, and over 20,000 older than 100. Whereas in 1941 there were only 200,000 old-age pensioners, in 1982 there were 35,000,000 of them. By 1990 the country's population is expected to include nearly 50 million old and very old.

The articles in this Part of the collection are, however, by no means concerned with the demographic aspects of this phenomenon. Rather, they discuss the physiological aspects, the working of the genetic program which the organism abides by. Is the self-regulating system of life faultless? What are the errors in life control function? And how does the organism counter these errors? What is very important, is it possible for man to know the genetic program and amend nature by skilful interference so as to make the old age active and healthy?

The contributions to this Part of the collection describe a comprehensive approach to studies of the old age, the most interesting experimentation in the Gerontology Institute

of the USSR Academy of Sciences, and the nearly realistic "overhaul of man" in the future.

The few articles on the cybernetics of life can by no means exhaust all the topics in this field. This collection will hopefully serve a more modest purpose of giving the reader a taste of advanced biocybernetic and physiological modeling, and of psychological studies.

V. Pekelis

I. Biology and Information

Biology Today

Basic Tendencies in Physico-Chemical Biology

YU. A. OVCHINNIKOV

It is not unusual to hear or read that the 21st century will be the Age of Biology. This promise is certainly debatable because it assigns secondary importance to truly momentous achievements in physics, mathematics, and chemistry, in engineering and in other fields of knowledge; nevertheless, it would be difficult to argue against the salient fact, namely, that the recent discoveries and accomplishments of biology are revolutionary in spirit and epochal in their scale and import.

The scope of interests and problems in today's biology is extremely wide: from elementary processes in the living cell to the development of the entire organism, to its interaction with other organisms and the environment in the ecological system. Today's biology is a rapidly evolving branch of science, rich in exciting problems and prospects, commanding an army of enthusiasts, and armed with the most advanced techniques and equipment. Biology holds key positions in solving the global problems mankind confronts, be it the battle against fatal disease, the food crisis, or the pollution of the environment.

Biology is progressing very rapidly, but the rate at which one of its disciplines is moving ahead is incomparably high. This discipline, which matured in the 1950s, is the physico-chemical biology.

The "Visiting Card" of Physico-Chemical Biology

The birth and development of this branch of the biological science inaugurates a new era in the investigation of living matter. This event, being one of the most remarkable in the history of natural sciences in this century, is in the spectacular penetration of the ideas and techniques of physics, chemistry, mathematics, cybernetics, and other such fields into biology. This swift breakthrough into the world of fascinating biological structures and giant molecules with their unique properties was possible due to the superior power of human mind and the tremendous potential of modern technical means.

Physico-chemical biology is perhaps the first scientific discipline in which man recognized for the first time the unique dynamic architecture of the higher form of matter and was able to shed light on the extraordinary mechanisms that serve to ensure high efficiency, precise coupling, self-regulation, and reliability of the living cell systems and of the entire organism. A new qualitatively different stage has begun in our materialistic interpretation of the living nature, even though nature only partly unveiled its mysteries. This is the stage of direct analysis of the most profound biological processes.

The era of physico-chemical biology is characterized by the development and rapid progress of a family of interrelated scientific disciplines which draw upon the accumulated experience and employ the achievements of all modern branches of science.

The writing on the "visiting card" of physico-chemical biology is the union of biochemistry and biophysics, molecular biology and biological chemistry; indeed, physico-chemical biology came to life as an interdisciplinary science at

the hottest points of contact between these four disciplines.

The rapid progress of the science studying the living matter was brought about by the joint effort of the sciences dealing with the physico-chemical life-sustaining processes. The world of biological molecules, both small and gigantic, evolves as a self-consistent system with clear-cut distribution of roles played by individual subsystems and elements and with dynamic relations between information, physiological, and functional processes. Today's biology is already able to explain such immensely complicated life-sustaining phenomena as transfer of hereditary information, release and transformation of energy, transport of compounds and ions, propagation of nervous impulse, and many others. The explanations it supplies meet the most stringent criteria imposed by physics and chemistry.

Learning the Structure to Know the Function

One of the central problems of physico-chemical biology is to decipher the structures of biologically significant compounds which participate in biochemical transformations within cells. Indeed, the capacity to carry out a specific biological function was encoded by evolution into the structure of biologically active substances. The way to comprehending the living matter is to find out its structure. This path is full of thorns, it demands time and devotion, sophisticated methods and equipment. Actually, all efforts and expenses are justified because the deciphering of a structure paves the way to understanding most complex phenomena and events, and the mechanisms that make them possible. Suffice it to recall the epochal significance

for molecular biology of the deciphering of the double-helix structure of the deoxyribonucleic acid molecule (DNA), or of the determination of the amino acid sequence of insulin which was the starting point for the work on protein structure.

Scientists are attracted to various levels of the structural organization of the living matter, but mostly to the structure and spatial arrangement of biologically important molecules and the mechanisms of formation of molecular complexes and ensembles. We obviously need to know how these structures change in time, i.e. to know the dynamic parameters and to have a precise kinematic description. Finally, it is necessary to discern the relationship between the structure and the biological function it represents. These problems cannot be solved unless the researchers mastered the whole spectrum of structural analysis techniques which often involve a cybernetics approach to problem description, complete automation of the experiment, and employment of a computer. Structural analysis invariably calls for months or years of intense labor; the romantic world of daring hypotheses becomes accessible only after the obtained concrete data have been decoded, and when imagination is fuelled and steered by the results supplied by physics and chemistry. In fact, the scope and sophistication of structural analysis characterize the maturity of physico-chemical biology, the basic truth, and the reliability of its concepts and conclusions.

By now the primary structure (the amino acid sequence) of hundreds of simple and complex proteins has been determined by the joint effort of scientists in a large number of countries. These very important biopolymers are responsible for all principal functions of organisms. Soviet scientists significantly contributed to "uncovering" protein structures. Notably, one of the first deciphered structures of ribonucleic

acids (RNA) (that of valine) was determined in the USSR.

The improvement of express analysis techniques for deciphering the nucleotide sequence of DNA, leading to a steady determination of DNA structures is another complex and difficult task. At present we know the sequences of a number of large DNA fragments (of several thousands of nucleotides each) and of several viral DNA molecules. For example, the Shemyakin Institute of Bioorganic Chemistry and the Institute of Molecular Biology of the USSR Academy of Sciences reported the nucleotide sequence of an important regulatory fragment of the DNA of one of bacteriofages. The length of this fragment was about 1300 pairs of nucleotides.

The work on deciphering DNA structures unravelled a good deal of surprising results in the mechanisms of recording and transmitting information in biological processes. For example, it was found that genes do not necessarily form a sequence: one fragment may belong to several overlapping genes. Furthermore, a sequence of nucleotides in DNA genes is not necessarily a continuous code for the sequence of amino acids in a protein, since parts of the sequence that codes for the protein can be separated and found in different parts of DNA.

The flux of information on DNA structures remains vigorous and keeps filling more and more pages in the Book of Biology.

In this connection we should praise the substantial achievements in the study of the spatial structure of biopolymers and bioregulators. The structures of a large number of biologically important compounds have been deciphered by using X-ray structural analysis, nuclear magnetic resonance, UV and IR spectroscopy, and other modern high-precision techniques.

Genetic Engineering Revisited

The problems of genetics, which is defined as the science of inheritance and variability, are among the best investigated problems in physico-chemical biology. It is a well-known fact nowadays that the "genealogical tree" of each organism is written into a giant DNA molecule as a specific sequence of nucleotides. Relatively short messenger RNA molecules are synthesized on the DNA matrix; the process is catalyzed by enzymes. Special organelles of cells, called ribosomes, make use of these RNA sequences to assemble the appropriate proteins. Each property of a living system corresponds to a specific protein.

Soviet scientists made a very significant contribution to the study of the mechanisms of storing and transmitting the inherited information. Thus they discovered important features in the structure of the genetic machinery of microorganisms and some higher organisms, analyzed in detail the mechanism of RNA synthesis, and discovered informosomes, i.e., the complexes of messenger RNA and proteins; now the structure and functions of ribosomes are being studied, and techniques for isolating individual genes worked out.

The physico-chemical approach in genetics opens new vistas for medicine, agriculture, and other applied fields.

The greatest asset of modern genetics is the creation of genetic engineering some ten years ago. Now scientists attempt to restructure the genetic machinery in the desired way, so as to design new genetic systems.

Is there a point in "playing" with this "biological erector set?" There certainly is, and an important one.

The methods of genetic engineering make it possible to decipher and clearly demonstrate the arrangement and the mechanisms of functioning of the genetic apparatus of cells,

and to specify the function of each gene. Of no less importance is the feasibility of creating in the future "tailored" organisms with properties ordered by the scientist (e.g. useful microorganisms), eliminating the inherited "defects" of plants and animals, and assisting in the treatment of hereditary diseases of man.

Gloomy predictions for genetic engineering were voiced in the West. This attitude stems from the threat of growing, unintentionally, agents dangerous for man, as a result of manipulations with genes of microorganisms.

Indeed, the highest skill and profound understanding of a problem are not sufficient for experiments in molecular genetics; the experiment must be run under certain strictly controlled and monitored conditions. Stringent guidelines for the genetic engineering research were enacted in a number of countries, including the USSR. If these constraints are met, the safety of the personnel and the environment are guaranteed. The objections raised aim at social and ethical aspects rather than scientific ones. It would be hardly possible or useful to fence in the development of genetic engineering; rather, it should be made to improve the life of mankind.

"Nervous Impulse" and "Ion Channel"

Physico-chemical approaches have recently proved to be fruitful in such fields as studies of the nervous system and higher nervous activity, and the analysis of immunity, i.e., in studying the processes in which informational aspects play an important role. In the USSR this field is studied within the framework of two all-Union programs, "Nervous Impulse" and "Ion Channel", which are coordinated by the Interdisciplinary Science Council on the Problems of Phys-

ico-Chemical Biology and Biotechnology sponsored by the USSR State Committee on Science and Technology and the Presidium of the USSR Academy of Sciences. This research comprises the study of biological membranes. Membranes surround a living cell, its compartments and its organelles, and create there the conditions different from those in the ambient medium. Membranes are mostly built of lipids and proteins; among the functions important for the organism, biological membranes are responsible for the transport of nutrients and ions into cells and out of them. Membranes confront and identify foreign agents, viruses, and drugs, sense the signals coming from the environment, and serve to release and transform energy. They participate in the transmission of nervous impulses, in the formation of responses to hormones, in creating intercellular contacts, and in numerous other processes.

The electrical and chemical membrane mechanisms responsible for the generation and propagation of nervous excitation have been unravelled, and specific regulators of nervous impulse transmission discovered. As a result, methods of treating various mental and nervous system disorders were suggested. Toxins secreted by snakes, scorpions, and some sea organisms, capable of very selective interaction with the most sensitive parts of nervous systems, seem to be very promising objects for such studies.

Unique compounds, called neuropeptides, were recently discovered in the brain of animals and man. These substances can function as regulators of sleep and memory, can cause and releave the sensation of pain, fear, alarm, etc. Relatively simple chemical compounds thus participate in very complicated manifestations of the higher nervous activity, supplementing the electrophysiological mechanisms of inhibition, excitation, and recognition. Some of these compounds have been isolated in pure form, their structures were estab-

lished, and they were even synthesized in laboratories. These "chemical" aspects of brain functioning, which made a good number of older concepts obsolete, deserve greater attention on the part of neurophysiology which is too often "anchored" to traditional interpretations.

Biotechnology

The recent decade witnessed a sort of "boom" caused by the advent of the modern biotechnology. A highly mobile, efficient, and compact branch of industry has grown on the latest achievements of biological sciences, using, above all, the methods of genetic and cell engineering.

Biotechnology is a field intensively persued in the USSR; the basic economic guidelines for 1981-1990 specially underline the importance of biotechnological methods for national economy.

Let us consider several examples of the potentials of biotechnology.

First, biotechnology can produce industrially such unique bioregulators, previously unavailable, as insulin, interferon, growth hormone, etc., for medicine and agriculture.

Severe forms of diabetes, which affect tens of millions of people on the globe, are treated with insulin of animal origin. Since the animal and human insulins have somewhat different structure, the patients often suffer from severe allergic reaction to the "foreign" substance.

Attempts to synthesize human insulin had to be abandoned for reasons of prohibitive cost. The solution to the problem was recently indicated by genetic engineering. The insulin gene was isolated from a human cell. This gene was inserted into the DNA of conventional colon bacillus, E. coli, so that the fermentation tanks of biotechnological plants

became sources of the unique human insulin. Preparations of this "microbial" insulin are now being studied by medical practitioners in a number of countries, including the USSR.

Interferon is an even more spectacular example. Interferons are natural antiviral proteins which are produced by an organism in response to a viral infection. In pure form these proteins are practically inaccessible. The best source of human interferon is donors' blood. Actually, patients suffering from viral infections require so much interferon that this amount would be impossible to obtain even if all people of the Earth became donors.

A different approach had to be found. As with insulin, scientists turned to the "DNA industry" and cell engineering. Interferon genes were isolated in laboratories of a number of countries, including the USSR, and pioneer experiments on "inserting" it into E. coli were carried out successfully. The stage of direct chemico-enzymatic synthesis of the gene of human interferon has been completed in this country, and first batches were manufactured on an industrial scale.

Work on deciphering, isolation, and transplantation of nitrogen fixation genes is also very promising. Some microorganisms, such as nodule bacteria, are capable of digesting atmospheric nitrogen when in symbiosis with certain plants (notably, leguminous plants). If it were possible to transplant genes of this type into the genetic apparatus of other microorganisms and cereal crops, the problem of nitrogeneous fertilizers would be largely alleviated, producing a virtual revolution in agricultural production. This line of research is pursued at a number of research centers, including the USSR Academy center in Pushchino.

Techniques available to modern science make it possible to cultivate in special nutritional media not only populations of microorganisms but also those of plant and animal

cells. A complete plant can be grown, and biomass comprising all components of a mature plant organism obtained, from a single plant cell under appropriate conditions.

Physico-chemical biology and biotechnology are two closely interrelated areas of modern biology, being its growth points and its horizons. It would not be an exaggeration to say that today the state of the art in biology and biotechnology determines, to a great extent, the scientific and technological potential of our country. Our achievements in this field are truly impressive.

Genetics, Evolution, and Theoretical Biology

N. V. TIMOFEEV-RESOVSKY

An entirely new approach came to replace in the 20th century the former physical picture of the world, the picture which is in fact embodied in the familiar Laplacian determinism philosophically "adapted" in the Auguste Comte's positivism. The current outlook has not been "officially christened" yet, and we refer to it as the quantum-relativistic standpoint, since it rests on the modern quantum theory and theory of relativity.

Imagine the absolute Laplace-Comte determinism: every tiniest motion is prescribed by some "world's formula" that we are unable to use either owing to our ignorance or for a lack of data. Correspondingly, neither the freedom of conscience nor the freedom of opinion exist: indeed, any possible correct proposition is already contained in that formula. It would be quite silly to write a paper; suffice it to request

a mathematician to derive from the general formula (and several thousands of auxiliary formulas which help to use the main one) the statements that the present article offers to the reader.

Determinism of this sort essentially renders any practical activity meaningless. Indeed, the society need not formulate any objectives, since everything had been recognized and predetermined by the universal formula. Obviously, man has no place in such a world.

The new physical picture of the world is radically different: it does not preclude the freedom to plan our individual, collective, social, political and economic activities, and also the freedom of conscience. This picture is one of the main achievements of natural sciences in this century, even if it is not recognized as such by everybody. The main achievement of biology was the development of genetics.

* * *

Genetics was born in the 20th century as a belated though vital link in the mechanism of evolution that the genius of Charles Darwin discerned more than a hundred years ago. Darwin indeed saw the principle of selection in nature, and this succeeded in laying the foundations of evolution theory. Darwin clearly stated in the title of his most important treatise, "On the Origin of Species through Natural Selection", that the way to construct the theory is to apply the principle of natural selection to some "individual variability", i.e., to a nondirected statistical process involving equally well the most general and the most specific tiny details of living organisms. In fact, that was what Darwin did.

Unfortunately, nothing was known in Darwin's time about the elementary material for selection. There was practically

no cytology, chromosomes were unknown, and the principal paper of Mendel was published later than Darwin's book. It looked as if Darwin's titanic research had no foundations: the theory of evolution rested on an uncertain variability of quite unknown nature.

Mendel's genetic rules were rediscovered at the end of the 19th and the beginning of the 20th century, in five different countries and with 19 different objects. All speculations about the spurious origin of these observations were, therefore, silenced and Mendel's mechanism of heredity emerged as a general law of nature. Time was right for starting the construction of evolution theory.

In this connection we should recall the illustrious school of American cytologists created by E. B. Wilson (it was the best among the German, British, and American scientific schools) whose scientists completed the first step of studying the cytology of meiosis, that is, of the maturation of sex cells, and the cytology of fertilization. In 1902 Wilson published in *Science* a short note where he drew the attention of the scientific community to the observation of his colleagues W. S. Sutton and C. E. McClung. Namely, they found that meiosis and fertilization were nothing else but a cytological confirmation of Mendel's brilliant hypothesis on hereditary factors and gametic purity.

There is a similarity in Darwin's and Mendel's scientific fates. In contrast to frequently expressed incorrect opinion, Darwin was not the author of the concept of evolution, which had been expressed much earlier by Aristotle, Linnaeus, and many other predecessors. His genius was in that he was the first to discover the principle of natural selection, a natural mechanism for the evolution of living things with time. Likewise, Mendel's genius was not in discovering the law of heredity, although this opinion is frequent and incorrect. Before Mendel's work, these laws were known to some pract-

ising selectionists. His genius was in conducting, for the first time in experimental biology, a set of well-conceived experiments, exactly evaluating the results obtained, and formulating the gametic purity hypothesis. The result was a clear and unassailable interpretation of the data obtained in the experiments with pea plants.

Evidently, Mendel's work and especially Darwin's analysis can serve as a foundation of the future edifice of the theoretical biology.

* * *

At present, we are not yet equipped with a theoretical biology as compared to theoretical physics. The discipline which is sometimes referred to as such has been known since the 19th century as general biology. Textbooks on general biology, which later became classic, were written at the onset of this century. Those books were "General Biology" by M. Hartmann and "General Zoology" by A. Kühn in Germany, a number of monographs by J.B.S. Haldane and J. S. Huxley in Britain, and an excellent treatise "Biological Foundations of Zoology" by Vladimir Shimkevich in this country. None of these books are obsolete today (wrong are those who think Darwin is out-of-date; actually, reading "On the Origin of Species" today is of greater use to every biologist than a booklet about Darwin's work even if it has been written only half a year ago). Later L. Ya. Blyakher published an extremely good textbook of general biology, and C. Villee's "Biology", translated into many languages, proved to be extremely successful in recent decades.

Theoretical biology does not exist—or did not exist until very recently—because we failed to find (at least until very recently) the general natural biological principles that would be comparable with the principles reigning in physics ever

since the 18th century. Apparently, only two such general principles can be identified at present in biology.

The first such principle (it has been known for more than a century) is undoubtedly that of natural selection. Time and again arguments flare up on whether this Darwinian principle is valid or needs replacement, but the doubts never stand up to serious scrutiny. "Normal" biologists do not fight about natural selection. Perhaps, only mathematicians not steeped in biology can accept, and try to prove, that evolving nature could do without natural selection.

Biology has at its disposal another general natural principle, even though it is less well known so far than the principle of natural selection.

It became clear at the end of 1920s and the beginning of 1930s that whenever living things reproduce, creating their likes, we invariably find the replication of molecules. This understanding was achieved by Max Delbrück and later by Paul Dirac (one of the members of the famous Copenhagen club of physicists and mathematicians clustered around Niels Bohr) on the basis of the physico-chemical model of chromosomes and genes developed by N. K. Koltsov. In contrast to crystal growth, which also involves the replication of molecules, the process unique to living matter is called *reduplication*. One of the main manifestations of life is the growth in the number of elementary individuals, rather than in the mass of the living matter. In this process and elementary living being assembles its like and rejects it, thus launching into the world a new individual. Reproduction is not an adequate term for this process, reduplication being a much better one.

After the advent of genetics in the 20th century it became clear that all organisms are subject to a spontaneous mutational process, that mutations are inherited, and that reduplication passes them on to subsequent generations. In

our discussions with Delbrück and Dirac about the possible formulation of a general biological principle revealed in this process, we came upon a phrase which seems to be very convenient, namely, *convariant reduplication*, or reduplication of living entities which includes inherited variations. It became clear that convariant reduplication of discretely organized codes of genetic information is likely to represent the second general biological natural principle.

So far this formulation is neither sufficiently rigorous no quite pe fect. Nevertheless, even at this stage it is evident that two general biological natural principles are established. One is the natural selection, and the other can be christened, in a tentative fashion, the principle of convariant reduplication of discrete codes of hereditary information which is transferred from generation to generation.

* * *

In my opinion, it is justifiable to offer for discussion an additional biological phenomenon which is very promising from the standpoint of formulating a third biological principle. This phenomenon concerns the problem of so-called *progressive evolution*.

As a concept, progressive evolution still lacks not only a rigorous or exact, but even a minimally acceptable, reasonable, logical definition. So far biologists did not deign to put in words what progressive evolution is.

I think, the question is, whether the natural selection operating for a long time necessarily results in progressive evolution or not. Here, a full-size mathematical problem arises in biology. Until now biology gained very little from most of mathematical biology, or biological mathematics. In fact, skillful manipulation of mathematical formulas

fails to add to a profound understanding of the core of biological processes.

I recall an interesting illustration. At the end of 1920s and the beginning of 1930s I took part in the development of the fundamentals of the modern physico-chemical form of the interpretation given to the principles of hit, target, and amplifier in radiobiology. A group of scientists at the German Institute of Metal Physics was interested at the time in applying mathematics to radiology. About 20 short papers were published, each containing about 20 formulas that were hardly comprehensible to biologists. I was partly responsible for attracting to this work first Max Delbrück, a student of M. Born and N. Bohr, who was originally a "pure" physicist and mathematician, and later Werner Heisenberg. After roughly a year of meetings of our colloquium, we achieved profound understanding of phenomena and of the description of processes, so that in subsequent publications the number of formulas dropped from 20-25 to 2-3. The famous French mathematician Henri Poincare once said—and later I heard Bohr say the same—that if a scientist does not understand a problem, he writes numerous formulas, but when he reaches understanding, at best two formulas are retained.

I believe that the problem of whether the natural selection, which has an eternity to do its job, necessarily results in progressive evolution (we prefer to think that it does) can be solved by an outstanding mathematician, or a group of outstanding mathematicians, who are at the same time true philosophers. It seems that special mathematical methods have to be found, which would give a more or less definite answer to the question formulated above. The answer may equip us with a third natural principle which could be employed for developing the theoretical biology. I had played an active role in formulating the second principle,

As for the third one, no one of the contemporary scientists seems capable of giving a serious answer to the question about inevitability of progressive evolution in the course of natural selection.

* * *

Before handing this problem to mathematicians, biologists first have to give a definition of progressive evolution, and second, to clarify whether different types of evolution are possible. Evolution on our planet followed different paths. Thus, it led to the mechanism of the higher nervous activity typical of man, but it also produced a fascinating organization of social insects. Life on the Earth could be very different if the evolutionary victors, and in a certain sense "kings of beasts", were these insects. For example, the notions of morality and heroism would be meaningless: a bee that stings and thereby perishes is not a hero because it was meant to behave in this manner and equipped with special tools and weapons. Neither would there form those notions of ethics and those sublime categories which exist and will exist as long as the Earth is populated by people having a freedom to choose and a freedom to make decisions.

We, biologists, stand in need of formulating (defining) a number of concepts that are involved in the formulation of the general natural principles which are required for developing theoretical biology. This done, we will enter the period of elaborating most diverse general schemes for constructing a theoretical biology which would be something above mere "general biology".

Future will show whether additional general biological principles (on top of the three named above) are necessary. Nevertheless, the evaluation of the theory of evolution promises to become the first task of theoretical biology. When this job is done, biologists will be able to single out

and understand what conditions and what additional factors channel and shape the progressive evolution which is the product of natural selection.

Transition to Constructing Living Systems

A. A. BAEV

The interpretation of traditional problems in biology became more enlightening when the concepts of information, encoding, control, and feedback were used, and the philosophy of cybernetics as a whole was applied to biological systems. An even more significant factor was the formulation and solution of new problems, such as the deciphering of the genetic code.

The ideas of control engineering constitute an important component of research programs and methods in modern biology. Besides, observation lost the status of the predominant channel of gaining biological knowledge. Experiment found its way into biology, although sometimes it creates only very approximate models of actual situations. Biology, this traditionally descriptive science, was transformed into an experimental science.

One of the most stunning discoveries, which led to the advent of a discipline called *genetic engineering*, was the product of experiment. This new branch of molecular biology opened up totally unexpected vistas in studying hereditary effects, but at the same time it led to numerous debates on whether the outcome of genetic-engineering research will be a blessing or a bane.

Genetic engineering aims at assembling man-made genetic structures, and ultimately, at growing organisms endowed with novel hereditary properties. This research turned experimental biologists for the first time into designers of living systems, who control the genetic information according to a predetermined program.

The dream of Middle Ages was to synthesize a homunculus, or a tiny artificial human being. Alchemists relied on black magic. We live in a different age, and connect our hopes only with moderate potentials of experimental biology. Accordingly, we impose limits on our dreams. Nevertheless, genetics engineers will soon grow, beyond doubt, into the shoes of chemical synthesis specialists who left a long time ago a variety of compounds prepared by nature and created a huge kingdom of man-made organic compounds.

The achievements of genetic engineering are still modest, especially in comparison with the outlined research programs, and yet they are very impressive. Indeed, they show that contemporary biology is no longer satisfied with interpreting, or reflecting, the surrounding world of living things and man as its component; biology turns into a practical tool for changing this world in order to better satisfy the needs of population.

Lessons of Genetic Engineering

Genetic engineering can be defined as a system of experimental techniques which make it possible to assemble in vitro artificial genetic structure in the form of so-called recombinant (hybrid) molecules of deoxyribonucleic acid (DNA).

A living cell is essentially a tiny chemical plant whose technological process is dictated by a hereditary program

written into one of its nucleic acids, namely, DNA. Physically and functionally, the program consists of blocks, or genes, each of which controls the synthesis of a specific product (typically, of a protein) and the execution of a specific function which is controlled by this product. The introduction of new genetic information into the cell by recombinant DNA molecules changes the "inherited features", so that the experimenter obtains the organism adjusted to a specific task.

It is an extremely complicated job to identify the required genes in DNA molecules (which are huge even in the simplest organisms) and then extract and assemble them into a functioning structure. Tools suitable for this work are very subtle. These are enzymes designed by nature and contained in living cells. Some enzymes (called restriction endonucleases, or *restrictases*) "cut" DNA molecules at very specific sites into longer or shorter segments, and enzymes (called *ligases*) join them into a single chain. The synthesis of artificial genetic structures became a feasible task after such ferments were isolated from cells and purified.

In outlining the chain of events leading to the rise of genetic engineering, it is necessary to emphasize that it did not spring Aphrodite-like from the foam and did not introduce either a new approach to biological phenomena, or new cognitive ideas, or the need to throw out the traditional set of concepts (meaning current concepts, not those prevalent in 1940s). The understanding of inheritance mechanics and the problems of this field remained the same but the possibility of penetrating deep into the phenomena was drastically enhanced. It was as if the key to a locked door was found, and the research was free to advance. This does not mean, however, that new technology brought nothing new; on the contrary, completely unexpected discoveries were made at the very outset.

It was established that higher organisms, yeasts, and some bacteria have mosaic genes, i.e. genes which code for a specific protein but are interrupted by inserted segments (introns) which are not related to this protein. As a result of this structure of genes (quite typical for all higher organisms), the cell is the scene for the so-called processing which before this discovery was completely unknown. When the genetic information is realized, the gene is first copied (together with all inserted segments and informative sequences). This copy is called the precursors RNA (RNA stands for ribonucleic acid). Special enzymes then "cut out" all inserted segments and join the informative sequence into a "mature" messenger RNA. The corresponding protein is synthesized on this "edited" RNA molecule.

As the next step, the nature of transposons of bacteria (mobile genetic structures) and of mobile elements of higher organisms was established. These are the two most important results of recent years. The discoveries that the nearest future may bring can hardly be predicted. But we can be sure that discoveries are inevitable, and that they may force upon us the need to revise some firmly established dogmas.

Can genetic engineering be used to create new organisms? This is a typical question. We have already answered it in the affirmative, but some qualifications are necessary. Currently experimenter manipulates with relatively small amount of information. Even if this amount were considerably increased, the information carried by artificially synthesized structures could not be organized so as to produce a completely new organism.

So far our picture of the structural foundations of genetic control is very incomplete. Only a limited number of genes can be introduced into a bacterium, whose genetic status is thereby changed to a rather limited extent. However,

the possibility of introducing into a cell an alien information belonging to a different species, even a different type, changes the situation drastically. An E. coli bacillus carrying active human genes is definitely a new organism.

A feature typical of genetic engineering is that the reproduction of some key genetic processes in the laboratory was realized at the molecular level. A function entrusted by nature to an organism as a whole has been turned in laboratory conditions into an operation carried out at the level of a cell or a molecule. Experimenters treat genes without any mystic aura; for them a gene is a fragment of DNA either isolated from natural systems or synthesized in vitro. The recombination, or arrangement of genes into a new sequence, takes place in a glass tube, according to the choice and wishes of the experimenter. The role of the usually all-powerful random factors is then so constrained that becomes virtually negligible; the goal-directed activity of the scientist, his professionalism, his art turn into major factors. This intrusion into a formerly forbidden field cannot help impressing the community greatly, all the more so because we witness the very first steps of genetic engineering and thus could not get accustomed to its fascinating promise.

Genetic Engineering and Technological Revolution

The readers will remember that man employs biological processes since time immemorial, for instance, for fermentation in producing bread, wine, beer, and other kinds of food. In fact, this was biotechnology mastered empirically a long time ago.

Science, above all microbiology, grew to form the foundation of biotechnology in this century, or rather in its second half. Some achievements of biotechnology at this second stage of development are fairly well known. They include the production of fodder proteins from petroleum using yeasts, and the utilization of microorganisms for "extracting" enzymes, pharmaceutical products, vitamins, and so forth. It is less well known that plant cells serve to generate the active component of ginseng and some other physiologically active compounds.

The rapid progress of genetic and cell engineering gave shape to what is now called "modern biotechnology". This field is based on some fundamental results recently obtained mostly in the physico-chemical branch of biology.

An exceptionally important role played by genetic engineering in biotechnology follows from the unique method it offers for obtaining the required microorganisms and compounds, namely, the colonization of the microbial cell by the appropriate genes. If the genetic structure introduced into the microorganism becomes stable, this method becomes efficient and cost-effective. Despite the similarity of the elementary biological processes in the original organism and in the organism modified by genetic engineering, the genetic-engineering manipulations may result in final products that differ from the natural output compounds. Sometimes, nature has no analogs of the designed compounds.

The new biotechnology has another extremely important characteristic.

Until very recently the isolation of natural mutants was the only way genetics could use to enhance the productivity of microorganisms. Among the set of mutants, only the strains with useful properties were selected. However, the natural frequency of mutation is extremely low, about one individual in ten million. Besides, the properties of mutants

are very seldom better than those of the predecessors. Genetic engineering designs mutants according to a preconceived plan and a chosen objective. Here lie both the specificity and the advantage.

The possibility, at least in principle, of producing completely new types of plants is already a reality for genetic engineering. It is not yet clear, though, to what extent its methods will be effective for "designing" new breeds of farm animals. But even this prospect seems to be realistic, because part of the genes introduced into cells of animals were experimentally shown to be functionally active.

The next generation of protective measures for agricultural plants is also an important subject for research. We mean the development of compounds which are found in nature and which control the behaviour of insects; such are the sexual attractants, or pheromones, which are analogous to the juvenile hormone. These substances can disorient pests, disturb the normal course of their development, and even completely eradicate them when combined with other compounds. The advantages of the new plant protection methods are especially clear in comparison with fairly toxic and long-lived insecticides which have been employed in agriculture in the last decades.

To date the most advanced branch of biotechnology is the microbiological industry. Its objective is well-defined: to achieve exclusively industrial production of fodders and of physiologically active substances, and in the future, of human food as well. Mankind will not terminate the traditional agricultural production but will supplement it with the microbiological one. This combination can supply higher-quality food than currently available, and at lower cost.

Genetic engineering opens unlimited possibilities for the cooperation of biology and medicine. One of the uewer

problems is the treatment of hereditary metabolic disorders by transplanting to the patient his own cells carrying healthy genes. Obviously, only monogenic metabolic deficiencies are meant. Of course, considerable experimental search is needed for solving such a complex problem. It is clear even now, that cell transplantation has a number of advantages over the conventional transplantation. Namely, it is possible to obtain a viable cell from the patient, transform it, and transplant into it any gene of the same species.

The new biotechnology is responsible for giving birth to an unusual branch of pharmaceutical industry: the "DNA industry", which makes use of the processes based on genetic engineering technology. The method of recombinant DNA proved its unparalleled potential for the industrial production of medically important substances, such as human insulin, human growth hormone, vaccine against virus hepatitis, human interferon, and some others.

The hope of producing diverse substances of considerable medical and commercial value by the above-described techniques is becoming increasingly more realistic. Numerous obstacles undoubtedly lie on the way to converting the laboratory procedures into technologically and economically attractive processes, but earlier experience points to the possibility of overcoming them.

Such is the current stage in biotechnology which definitely manifests all signs of future growth. The next stage of development, even more ingenious and promising, is taking shape now. At this stage two mutually enriching lines of research are pursued: the study of the mechanisms of biological reactions, on one hand, and modeling these reactions in order to synthesize simpler physico-chemical analogs, on the other.

Genetic Engineering and Social Atmosphere

Situations which arise when new scientific ideas are injected into the social texture and into social practice may be very dramatic. A brief history of genetic engineering is quite instructive, even though it is not unique in this respect.

Once it was born, genetic engineering immediately attracted the attention of scientists, press, and general public, but not by virtue of its scientific achievements (which at the beginning was very modest) but for reasons of quite different nature. The issue was raised about the potential danger to mankind and environment, about the ethical and biological admissibility of a crude intrusion of man into nature's order.

The opinion that genetic engineering is a threat to society is rather widespread. What are the signs of danger attributed to recombinant DNA? First, it is assumed that the implanted alien genetic information may transform innocuous microorganisms (such as intestinal bacilli, E. coli) into pathogenic organisms. Second, microorganisms containing recombinant DNA are assumed to be able to acquire unpredictable ecological advantages and to shift the equilibrium of microbial populations in the environment.

The first of these options seems hardly probable because even though pathogenic microorganisms are harmful to man, they are perfect creations in their own right, rather than a nature's bungled job. Breakdown of ecological equilibrium appears more probable. Indeed, mankind proved very "proficient" in this respect, having disrupted, for example, the nitrogen balance and having introduced in the environment large amounts of pesticides which are required for the agricultural production but are fraught with harmful effects on the environment. Finally, it was conjectured that

microorganisms with implanted genes of some physiologically active substance, such as insulin, may colonize the gastrointestinal tract and result in treatment-resistant pathological states. In the long run, these apprehensions proved to be unfounded.

The hypothesis of the threat of recombinant DNA was mostly generated in the American scientific community. These scientists published during the Gordon Conference in 1973 a sort of a manifesto which declared the potential danger of "hand-made" DNA and argued for a moratorium, i.e. temporary halt in all recombinant DNA research until the real issues become clear. Very soon, a campaign against the hypothetical menace of recombinant DNA was organized in the USA. Sensation-hungry press, radio, and TV immediately got into the act, so the stand taken by the scientists was given good publicity. That was the start.

Let us emphasize that the anti-genetic-engineering campaign was running strong only in the USA. In all other countries, including socialist countries, the reaction was more restrained and balanced.

Later the American scientists broke into several groups. Some went on with their campaign as relentlessly as before. Others changed their attitude and engaged in concrete investigations aimed at assessing the danger posed by recombinant DNA.

The campaign has been terminated by now. Two factors contributed to this change: first, no experimental proof was obtained of accidentally arising danger of recombinant DNA, and second, genetic engineering proved its promise of the possibility of industrial application (outlined above). This argument was decisive for dropping the idea of rigid control in genetic engineering and ceasing to exaggerate the dangers.

It is important, nevertheless, to evaluate the extent to

which science is prepared to face the dangers involved in recombinant DNA if it is proved to be harmful or grows to be dangerous in the future. The experience accumulated in working with pathogenic organisms for more than a century conclusively supports the argument that science is adequately equipped with knowledge and techniques for protecting the personnel, the population, and the environment. It must be recognized that the initially voiced apprehension was exaggerated. Obviously, this does not mean that the research and, to an even greater extent, industrial-scale genetic-engineering technology can proceed without strict control and monitoring. A reasonable, sober assessment of the positive aspects and possible dangers of genetic engineering were predominant in the USSR from the outset.

Concluding Remarks

The advent of genetic engineering inaugurated a new phase in the evolution of experimental biology: its creative phase. Indeed, the biologist can now act as a creative personality, rather than a passive observer. As genetic engineering elaborates and refines its tools, the role it plays will undoubtedly increase; moreover, important unexpected breakthroughs in the understanding of the structure and functioning of the genetic system may occur in the nearest future.

Both genetic engineering and the whole family of biological disciplines usually joined under the title "physicochemical biology" are looking into the future with confidence. The world of artificial genetic structures will gain the status of a legitimate child of science and technology, as the world of man-made compounds, synthesized by organic chemistry, did some time ago. We believe that the collective wisdom of mankind will prevent any antihuman uses of genetic engineering.

In a wider context, the future of physico-chemical biology will be decided by man's attitude to his environment. Should original nature be destroyed by man's activities and the resultant anthropogenic environment prove to be very different from, sometimes, even opposing, the natural environment, then physico-chemical biology will turn into one of the main tools of reconstructing the surrounding world. If man follows the "habitual" path of preserving the natural habitat, physico-chemical biology will be successful in protecting the completeness and richness of the environment. Whichever of these two paths is taken by man in the nearest future, physico-chemical biology will serve him faithfully regardless of circumstances.

Autowaves: An Interdisciplinary Finding

G. R. IVANITSKY, V. I. KRINSKY, and O. A. MORNEV

Autowaves ("self-sustained waves") is a generalizing concept that was introduced into the field of waves and oscillations for putting in order the experimental data and theoretical notions about the mechanisms of some important processes observed in biology, chemistry, and physics.

The simplest example of what nowadays is referred to as autowaves is the combustion wave. The advancing fire wall of a forest fire is familiar to mankind from time immemorial. However, it was found only recently that the propagation of autowaves governs such dissimilar processes as transmission of information in living organisms, contractions of the cardiac muscle, initial stages of morphogenesis in some pri-

mitive organisms, processes of activation of catalysts employed in chemical industry, and many others.

The interest in studying autowave propagation is stimulated by the following important fact: the breakdown of regular modes of propagation and the interaction of autowaves result in disorganization and chaos in systems controlled by such waves. Thus, disturbances of this type may lead to grave cardiac arrhythmias.

The reason for separating autowaves into a special class of oscillatory processes is their clear-cut distinction from other types of waves known in science, e.g., electromagnetic and mechanical waves in liquids, gases, and solids. We know that wave motions in liquids are excited if certain energy is spent on the creation in the medium of the initial perturbation which then propagates as a wave. In the final count, this wave propagates owing to large-scale mechanical motions, obeying of course, the law of energy conservation. Consequently, the wave initiated by an external perturbation requires no additional energy for its propagation. This situation is naturally realized when we throw a pebble into the still waters of the lake: a part of the kinetic energy of the pebble is converted into the energy of the initial perturbation during that short moment when the stone breaks the surface of the water. If the lake is shallow, the ripples still run out while the stone is already at rest on the bottom.

The laws of propagation and interaction of wave perturbations in such media (conservative media) are especially simple in the case of low-amplitude sine waves. Such waves go unobstructed through one another, their interaction being reduced to algebraic summation of oscillations at each point of the medium (the superposition principle). This behaviour explains, among other things, the formation of classical interference patterns, i.e., a moiré pattern composed of oscillating region (at the points where the amplitudes add up)

and quiet region (at the points where the amplitudes subtract) of the medium (Fig. 1*a*). The same fundamental superposition principle leads to the other two characteristic properties of waves: reflection from obstacles and boundaries, and diffraction (propagation around obstacles).

The energy of the initial perturbation is indeed conserved in conservative media, but these media are not convenient for transmitting signals over large distances: in two- and three-dimensional media the energy density decreases as the distance to the source increases, and the shape of the signal is distorted by dispersion, i.e., the velocities of propagation are different for different spectral components of the signal.

All of the above-listed properties are modified in an unexpected manner as we go from waves in conservative media to autowaves. The table below shows that the only property common for the two types of waves is diffraction.

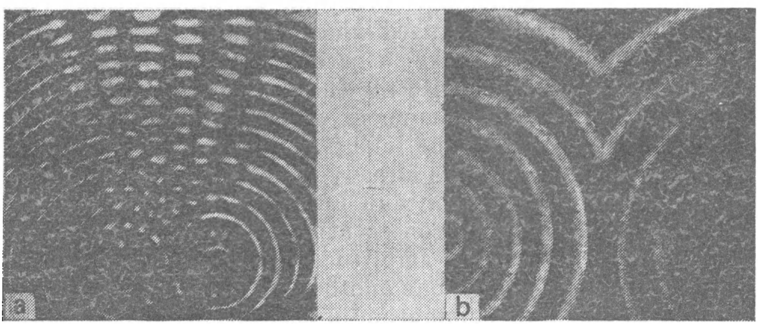


Fig. 1. Interaction between waves emitted by two sources
(*a*) interference of waves on the surface of water; (*b*) autowaves in an active medium do not interfere (colliding autowaves are seen not to propagate through each other as in Fig. 1*a*, but to annihilate)

Property	Waves	Autowaves
Conservation of energy	+	—
Conservation of amplitude and waveform	—	+
Reflection from obstacles	+	—
Annihilation	—	+
Interference	+	—
Diffraction	+	+

Note. "Plus" sign indicates the presence of a property, while "minus" indicates its absence.

What then is the autowave?

By definition, autowaves are waves propagating through active media, i.e., media with distributed energy resources. The simplest example of an active medium is the miner's safety fuse. Here the energy (chemical energy) is stored in the powder core, and the autowave is the combustion front travelling along the fuse. As the wave propagates, the substance of the core transforms from the stable high-energy state (unburnt powder) to the low-energy state (ash and gases left behind the combustion front). Part of the energy released within the combustion region is dissipated, while the other part is consumed for priming the burning of the consecutive adjacent elements of the still intact segment of the fuse.

The above example makes clear the following general definition: autowaves are self-sustained signals which initiate the processes of local release of stored energy which is consumed to initiate similar processes in adjacent regions.

Autowave propagation resembles relay races: the signal is reproduced at each point of the medium and therefore travels through the medium without attenuation or distor-

tion. The energy stored in the medium is not conserved in the process but is consumed for sustaining the signal; this explains the first two properties in the table. It is also clear why two colliding autowaves annihilate each other; indeed, the zone behind the wavefront of the travelling autowave in which the transition from high- to low-energy state takes place is the "burnt-out" zone (for the safety fuse, burnt-out in the literal sense of this word) where this transition has been completed. The oncoming autowave cannot penetrate into this zone, and thus two colliding waves annihilate each other (Fig. 1*b*). The impossibility of either interference or reflection from boundaries and obstacles is explained by similar arguments. As for the wave deflection around obstacles, i.e., the diffraction, autowaves are fully capable of it. This diffraction is explained here just as it is in optics, i.e., by Huygens' principle. The Huygens' principle for autowaves is formulated as follows: each pcint of the medium, reached at a given moment by the wave front, becomes the source of elementary circular autowaves; with annihilation taken into account, the envelope of elementary waves gives the position of the travelling wavefront at the next moment of time. This behaviour is illustrated in Fig. 2 which shows a standard construction according to the Huygens' principle (Fig. 2*a*) and demonstrates how the autowave front follows a curved boundary of the medium (Fig. 2*b*).

So far we gave only one example of an autowave: flamefront propagating through a combustible medium and converting this medium irreversibly into its "burnt-out" state. The so-called recuperating active media, in which slow processes convert the medium from the low-energy state (after the passage of the wave) to the original state, have more interesting properties. An important phenomenon is observed in such media: the formation of local self-sustained sources

(generators) of waves of the revolving vortices type which completely change the regime in the active medium. The nature and spectacular properties of such vortices will be described a little later. Let us begin with three examples of recuperating active media: a burner with slow-supply wicks, a chemically active medium, and a cardiac muscle. It will

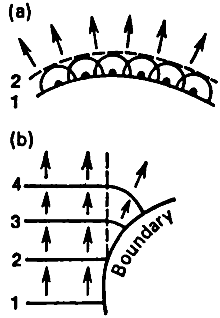


Fig. 2. Diffraction of autowaves
(*a*) Huygens' construction; (*b*) autowave follows the boundary of the active medium (successive positions of the wave front are marked with numbers)

be clear that the laws governing the propagation and interaction of autowaves in active media are independent of the specific physical realization.

Imagine a burner designed as follows. Strips of asbestos are inserted into holes drilled close to one another in a metal plate, the neighboring strips being in contact. The lower ends of asbestos strips are immersed into a batch of thick oil. Asbestos is nonflammable but serves as a wick when impregnated with oil. The rate of burning of the oil-impregnated asbestos wick is higher than the fuel supply rate. The flame will therefore soon die out. Later, diffusion will renew the oil content in the wick, burning can be restarted, and the cycle will resume. The wick can thus be in one of three states: burning; pause (refractory period) during which oil saturates asbestos; and the quiescent state in which the wick is ready to burn. If we ignite one of the wicks of our

demonstration burner, it will ignite the neighboring wick. The first wick will soon burn out (oil will be used up) but the flame front will propagate further on. This is an elegant way of creating a recuperating active medium: in contrast to the safety fuse, each element (wick) can flame up not once but an indefinite number of times. Note that the flame can be initiated not only by an external source but also by the travelling flame of the autowave. This is achieved if the sequence of wicks is closed into a ring; the flame then goes in a circle. If wicks fill a two-dimensional plane, a revolving fire vortex (a spiral combustion wave) is formed.

A chemical active medium was prepared by A. M. Zhabotinsky and A. N. Zaikin in 1970. It was a thin layer of a liquid in which the Belousov reaction occurs. In contrast to the majority of known oxidation reactions which proceed until one of the substrates (oxidizer or reducer) is used up, in this reaction a strong inhibitor is released which suppresses the reaction after only a small fraction of reagents is consumed. The inhibitor is then removed by slow processes, and the reaction can be restarted. This chemical medium is therefore active and recuperating, and the self-sustained oxidation wave can travel through it repeatedly, until substrate resources ("fuel") are used up. The Belousov reaction consumes about 1 per cent of the substrates per cycle, so that the oxidation wave can pass through the liquid about 100 times. In principle, the mechanism of oxidation waves is the same as that of combustion waves (burning is a particular case of oxidation): excited ("burning") elements of the medium excite ("ignite") neighboring elements.

Of course, the most interesting among active media are those created by nature. The best known example is the nerve fiber. The impulse propagating along the fiber is actually an autowave, namely, an electrochemical wave of transition between two states: the quiescent state in which the

potential difference across the membrane of the fiber is high (about —0.1 V) and the active state in which the potential difference is low (about 0.02 V). When a nervous impulse is sent, energy is successively released at each point of the membrane; its source is the stored energy of nonequilibrium concentrations of potassium and sodium ions on both sides of the membrane. Each nervous impulse has standard (for each cell) amplitude, length, and shape.

In addition to one-dimensional active media (nerve fibers), there exist two- and three-dimensional media composed of excitable cells which function as nerve fibers do.

Examples of such media are the brain and the spinal cord, nonstriated-muscle walls of intestines, womb and bladder, and also the cardiac muscle. Autowaves travelling through them have the same nature as waves in nerve fibers, differing only in impulse length and propagation velocity; however, they play very different roles in life-sustaining processes. The impulse travelling along a nerve fiber transmits information while the excitation wave propagating, say, through the heart triggers a cascade of biochemical processes which initiate the contraction of the cardiac muscle; the regime of contraction immediately changes in response to any change in the propagation of autowaves.

Populations of differentiating cells which exchange chemical signals, the retina of the eye, ecological systems, a number of electrochemical systems, and some others are also recuperating active media.

A fact of decisive importance is that the principles governing the functioning of all active media (physical, chemical, and biological alike) are found to be identical and can be described in terms of a language that avoids the specificities of a medium.

An active medium is invariably a two-level system that can occupy one of two essentially different states: a high-

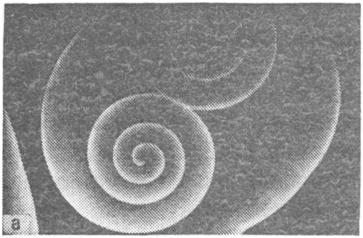
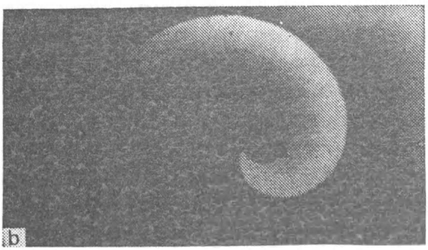
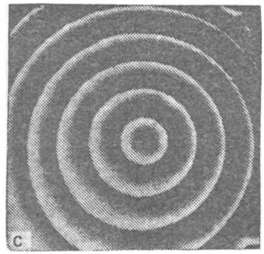


Fig. 3. Local sources of autowaves in chemically active media

(*a*), (*b*) spiral waves revolving in a simply connected medium, ("reverberator") (*a*), and around a non-excitable element of the medium (b); (*c*) source of concentric waves





energy and a low-energy states. When an autowave advances, the medium elements at the wavefront drop from the high-energy to the low-energy level. The energy released in this transition is consumed for triggering the same transition in the medium directly contiguous to the wavefront.

The simplest active media (nonrecuperating media) remain at the low-energy level after the transition, so that no repeated propagation of the wave is possible (e.g., the miner's fuse, or phase transition waves). In recuperating active media an autowave can propagate an indefinite number of times because slow processes of energy pumping return each element of the medium to its high-energy level.

In the case of the burner with low fuel-supply wicks the high energy level corresponds to wicks saturated with fuel,

and the low energy level, to the wicks with fuel exhausted (but fuel is stored in the jar into which the ends of wicks are dipped). The high-energy state of excitable cells corresponds to a large difference between the potentials of the inner and outer sides of the membrane (—0.1 V), and the low-energy state, to a small potential difference (0.02 V). Elements of the medium are usually non-excitable until the process returning the system to the high-energy state is completed; the corresponding time interval is called the refractory time (this term came from the physiology of excitable cells).

Let us explain how revolving vortices, the so-called reverberators, arise in active media. We have already mentioned that reverberators are the most important wave sources: the introduction of reverberators into an active medium can entirely change the mode in which it functions.

Figures 3, 4, and 5 give photographs of reverberators in active media of different types.

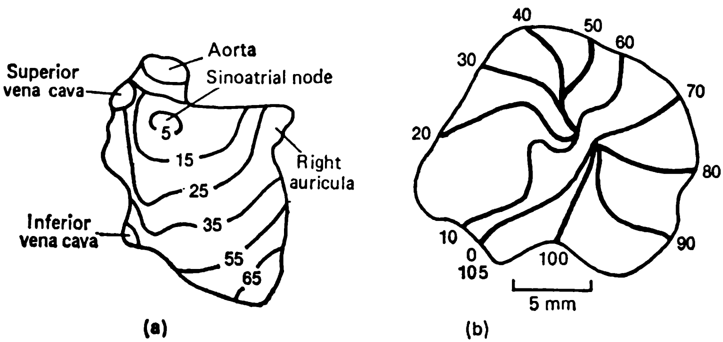


Fig. 4. Autowaves in atrium

(*a*) electric excitation wave triggering the normal contractions of healthy heart; (*b*) rotation of the autowave during paroxysmal tachycardia (M. A. Allessie, F. I. M. Bonke, F. J. G. Schopman). Heavy lines trace autowave fronts; numbers give time (in milliseconds) elapsed after the wave was started

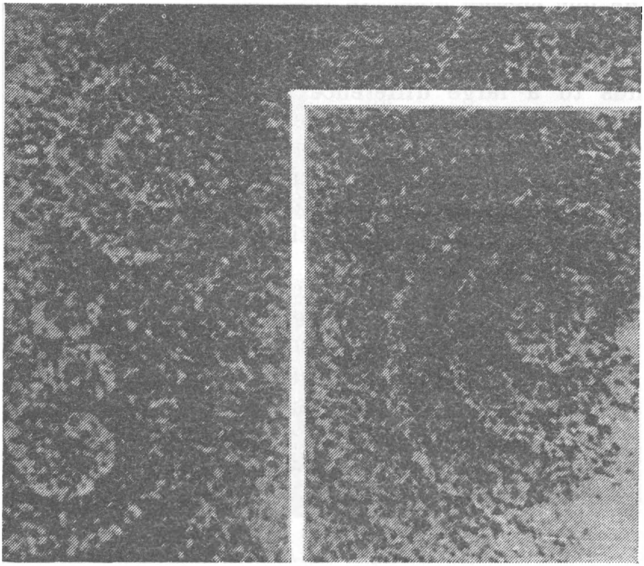


Fig. 5. Spiral autowaves formed in the process of differentiation of slime mold cells (G. Gerisch)

Reverberators are naturally arising in inhomogeneous media in which wavefronts break (rupture) in the course of propagation. Because of the discontinuity (Fig. 6*a*), quiescent regions of the medium lie not only ahead of the wavefront but also on the side, in the vicinity of the point 0. As a result, at the next instant the autowave moves upward but also sideways, penetrating into the region to the right of 0; Huygens' construction clearly shows how this happens (Fig. 6*b*). The envelope of elementary circular waves on the segment AB is clearly a straight line (the wave front has

been displaced, as predicted, upwards), while at the segment *BCD* it is an arc of a circle which terminates at the lateral boundary of the refractory zone at a point *D*. The incipient spiral is already apparent; finally it will coil into a reverberator.

Note that as time goes, the circular segment *BCD* expands, making the point *D* slide along the lateral boundary of the refractory zone towards the upward-moving back side of the wavefront, until they meet at a point 0′ (Fig. 6*c*). The second stage in the evolution of the reverberator spiral begins at this moment. The refractory "train" of the autowave to the left of 0′ moves upward, while the wavefront immediately to the right of this point moves downward; hence, a discontinuity appears in the neighborhood of 0′ right after the formation of the configuration shown in Fig. 6*c*. This discontinuity is immediately filled up by the wavefront revolving around 0′, by analogy to what we described above (see Fig. 6*a*, *b*). As a result, a complete turn of the spiral is formed after some time (Fig. 6*d*). As these processes are repeated, a reverberator with a greater number of wave turns is formed (see Fig. 3*a* or 9*d*).

A reverberator is a fascinating wave source: it can survive in a "stand-by" medium having no elements producing

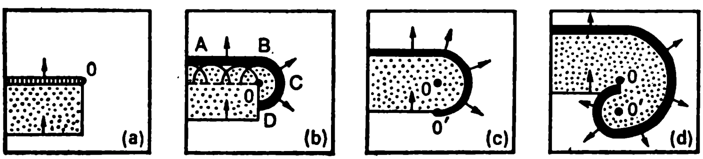


Fig. 6. Huygens' construction at a discontinuity of the autowave propagating in an active medium (I. S. Balakhovsky)

Arrows indicate the direction of wave propagation; a revolving spiral autowave, or reverberator, is finally produced

self-sustained oscillations. Furthermore, not being anchored to a geometrical feature of the medium (it is merely a revolving wave!), it can migrate in the medium.

A spiral wave revolving around an obstacle (see Fig. 3*b*) has similar properties, but in contrast to a reverberator it is anchored to the inhomogeneity at which it was born, and thus cannot migrate. Another type of source of autowaves is a source emitting concentric waves (see Fig. 3*c*); such are self-sustained oscillators of the active medium, surrounded by nonoscillatory elements.

Speaking of the properties of local sources of autowaves, we must not forget such a characteristic of a source as its topological charge. A source of circular waves (see Fig. 3*c*) is assigned zero topological charge. The topological charge of reverberators, however, equals the number of revolving spiral waves that form the vortex. In addition to vortices formed of a single helix (see Fig. 3*a*), "multibranch" reverberators are found to be possible; these vortices consist of several "branches" each of which is a helix revolving around the common center in the same direction. Photographs of such reverberators remind, to some extent, one of the photographs of galaxies. Compare a photograph of the M 101 galaxy from the Ursa Major constellation (Fig. 7) with multibranch reverberators in the Belousov-Zhabotinsky reaction (Fig. 8).

By definition, the topological charge of a reverberator equals the number of its branches taken with a "plus" or "minus" sign, depending on whether the vortex revolves clockwise or counterclockwise. The topological charge of a multiple-branch spiral wave revolving around an obstacle is defined similarly. If a medium contains several local sources of autowaves of various types, it is justifiable to speak of the net topological charge equal to the algebraic sum of topological charges of all sources. The following conservation

law always holds in experiments: interactions between local sources of autowaves do not change the net topological charge of the system (Fig. 9).

The mode of oscillation in an active medium containing several sources of autowaves is dictated by interaction processes. The source with the highest frequency suppresses all other sources, owing to mutual annihilation of waves. Among all local sources of autowaves, the highest frequency is found to be that of the reverberator. Consequently, it

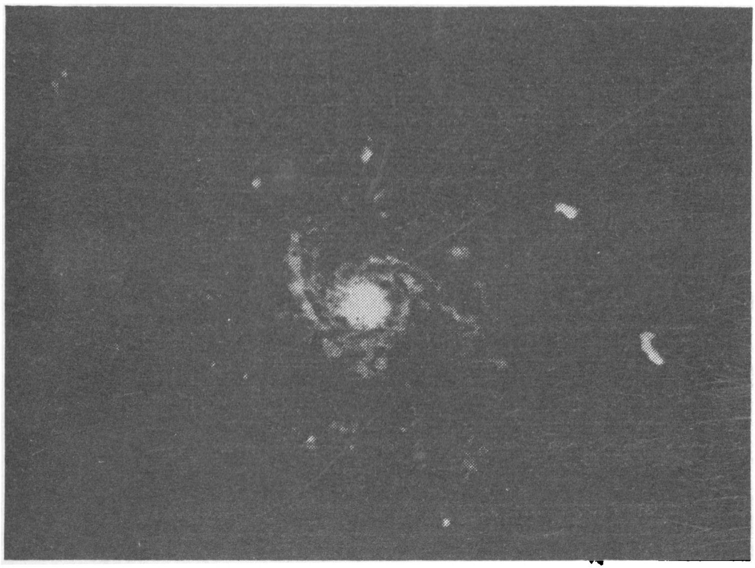


Fig. 7. Photograph of spiral galaxy M101 in the Ursa Major constellation

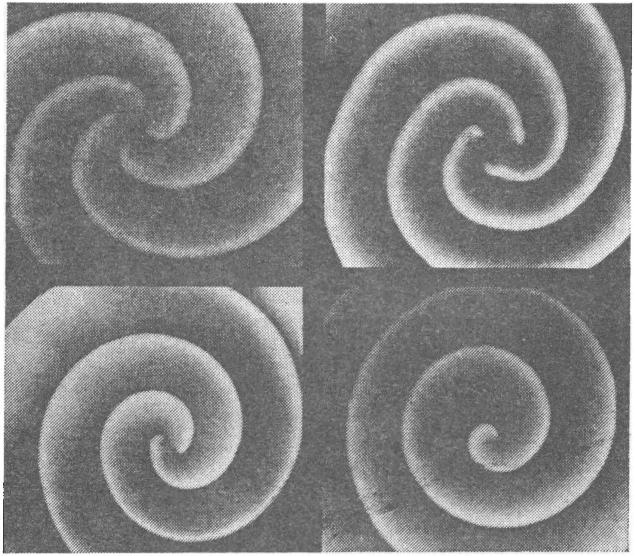


Fig. 8. Reverberators with various values of topological charge

forces its rhythm on the whole medium, suppressing, among other sources, all concentric-wave sources (Fig. 10).

Another important property of reverberators is that they can proliferate. We have already mentioned that a reverberator "coils around" a discontinuity "inflicted" by an inhomogeneity of the medium. If at least one reverberator is created in an inhomogeneous medium, the autowaves it sends out are broken on inhomogeneities, thus generating new vortices, etc. As a result of this cascade process the whole medium finally gets filled up with segments of revolving

spiral waves; the resulting chaotic pattern resembles a well-developed small-scale turbulence.

These two properties of reverberators produce disorganization of the normal functioning of biological systems. Is

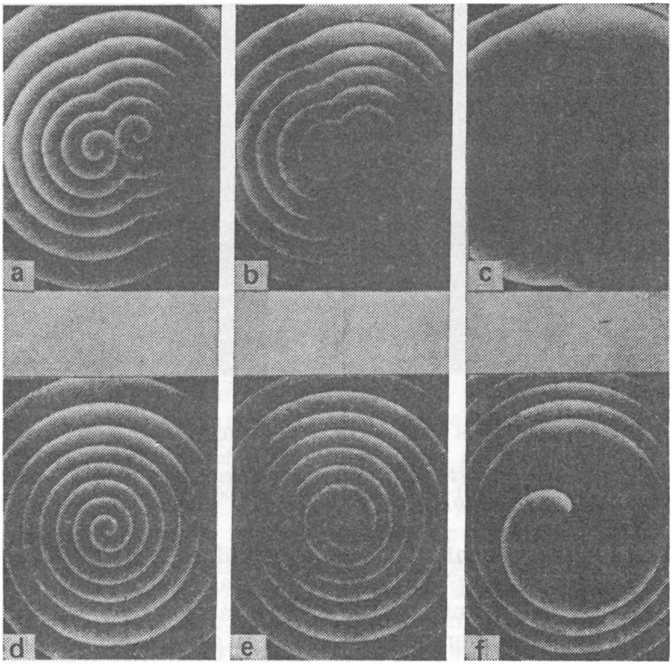


Fig. 9. Conservation of topological charge in vortex decay in the Belousov-Zhabotinsky reaction

(*a*) two vortices with opposite topological charges (the net topological charge $N = 0$); (*b*) a droplet of reaction inhibitor was added at the vortex center (seen as a dark spot); (*c*) vortices are destroyed, leaving behind a circular wave with the same topological charge ($N = 0$); (*d*) through (*f*) the same procedure cannot destroy a single vortex (the topological charge $N = 1$ is conserved)

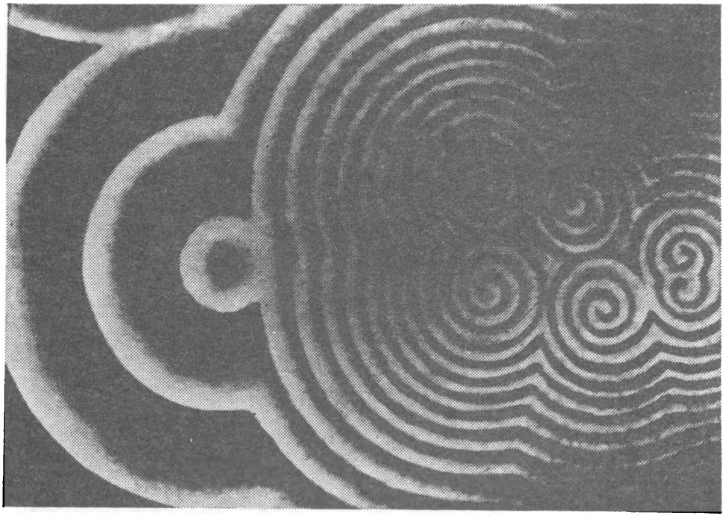


Fig. 10. Annihilation of a source of concentric waves by reverberators
As a result of annihilation by oncoming reverberator waves, none of the concentric waves is closed (reverberators have higher frequency); note that the next reverberator wave front will reach the source of concentric waves

it possible to prevent such failures and thus control reverberators' functioning? It is found that a reverberator can always be "muscled out" of the active medium by sending a high-frequency sequence of autowaves generated by an external source. Such waves make the reverberator drift in the direction of wave propagation (Fig. 11). This phenomenon can be utilized for "blowing" the reverberator toward the medium boundary: the vortex decays because autowaves are not reflected at the boundaries of the medium.

Let us consider examples of how different modes of auto-

Fig. 11. Control of the location of a reverberator in an active medium
(*a*) a high-frequency train of waves is sent onto the reverberator (from below); (*b*) the reverberator is transformed into two closely spaced discontinuities drifting upwards and to the right (*c*); (*d*) after the source of high-frequency waves is switched off, the reverberator is restored at a new location

wave propagation and the interaction between wave sources affect the functioning of some biological systems.

We begin with the work of the cardiac muscle. Under normal conditions the contractions of this muscle are controlled by a special source of excitation waves, the so-called sinoatrial node. This node is a group of excitable cells located in the right auricle and functioning in the self-sustained mode. Approximately once a second the sinoatrial node emits a circular excitation autowave (see Fig. 4*a*). The wave propagates through the auricles to the ventricles, causing synchronized contractions of these chambers.

The regularity of heart's contractions is disrupted, if autonomous vortex sources of autowaves (reverberators) are produced in it for one reason or other. Reverberators suppress the normal activity of the sinoatrial node and disrupt the regular rhythm of heart's contractions. It has been shown recently that this phenomenon is indeed observed in paroxysmal tachycardia, which is a severe cardiac arrhythmia caused by the circulation of a spiral excitation wave (see Fig. 4*b*).

Avalanch-like proliferation of reverberators in nonhomogeneous regions of cardiac tissue results in another severe form of pathology, namely, the ventricular fibrillation,

in which the synchronism of contractions of individual myocardial cells is lost, and the heart turns from a living pump into a chaotically jerking muscle bag unable to pump blood; this effect is a cardiac analog of the turbulent autowave mode in the Belousov-Zhabotinsky reaction.

Reverberators arise not only in the cardiac muscle. As early as in 1944 a study of epilepsy revealed the so-called spreading cortical depression (SD), or the wave of slow shift of the intercellular electric potential of neurons in the cerebral cortex. In the norm all cortical neurons exchange nervous impulses: the mind functions through the interaction between neurons. As a SD wave travels through the nervous tissue, the neurons first undergo an intensive discharge and then cease their activity, so that the functioning of the cortex is suppressed. A train of SD waves is a typical response to a powerful salvo of neuron discharges* which may be caused either by external causes (electric or chemical disturbance) or by purely internal ones (as may happen in an epileptic fit). The series may sometimes last for several hours. One of the mechanisms responsible for such a long train of SD waves is their reverberation.

This mechanism was recently confirmed in elegant experiments on chicken's retina. Retina is in fact a piece of the brain located at the periphery; it is capable of sustaining SD waves as the neuron tissue of the cortex is. These waves modify the properties of the retina so that reverberators (when they arise) can be photographed (Fig. 12).

---

* It is assumed that the SD effect is attributable to the accumulation of an excess of potassium ions in intercellular spaces; neurons are supposed to eject the ions in the course of intensive generation of impulses. The normal level of ion concentration is restored by energy-consumed ion pumps of the living cells which pump potassium back into the neurons.

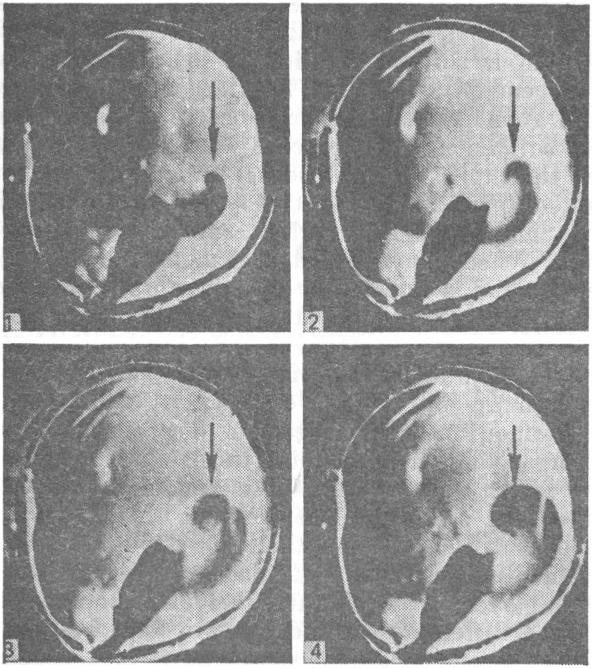


Fig. 12. Spiral autowaves in the chicken retina

It is noteworthy that in some cases reverberators assist in the creation of order in the initially disordered medium instead of generating "chaos" in it. This effect is observed in populations of slime mold (*Dictyostelium discoideum*) social amebas, presenting an instructive biological illustration of the self-organizing system.

The slime mold is a system which can exist, depending on

the external conditions, either as independently surviving single-cell amebas or as a single multicellular organism. If the medium is sufficiently rich in food, amebas live and feed independently without forming a coherent common organism. A sharp metamorphosis occurs when the food store is depleted. Then some amebas which have crossed the "hunger threshold" begin sending control signals into the medium, by periodically ejecting portions of cyclic adenosine monophosphate (cAMP) which acts as a chemical signal substance. When the cAMP "danger signal" diffuses through the medium and is detected by the receptors of other amebas, the latter turn round and start moving along the cAMP gradient, secreting it as they move. At the final stage of this process the whole population crawls together, individual amebas join up and form a single multicellular organism called plasmodium. This organism has rudimentary locomotion organs and starts moving in search of food (performing this faster than an individual ameba would). Having located a food store, the plasmodium "breaks down" into free amebas which resume their individual existence. If the plasmodium fails to find food, the reproduction program takes over, ensuring the survival of the species: the plasmodium differentiates and forms a fruit body, that is, a stem at the end of which spores grow in a special bag. After maturation, the fruit body bursts and the spores scatter around in order to live through unfavorable conditions and produce a new population of amebas.

It is readily noticed that in the course of cAMP generation the amebic population as a whole behaves as an active medium in which each ameba, detecting cAMP molecules and secreting in response new portions of cAMP into the surrounding medium, acts as an active element reproducing the "danger signal". In this context the cAMP concentration waves are nothing less than autowaves for which (as for any

autowaves of other types) all the above-described modes, including vortex modes, are possible. Vortices are observed in the structure of motion of migrating amebas (see Fig. 5).

Here again revolving reverberator vortices are the fastest of all local sources of autowaves, because autowave sources have identical properties in all active media, and all other sources are, therefore, suppressed. When a reverberator is formed, the amebas crawl precisely toward its center, and there the fruit body develops! This is an example how nature uses reverberators for building up a structure in extreme conditions.

The fact that autowaves propagating through various active media have common features and identical characteristics of local wave sources (with the mechanisms generating these sources, the interaction between them, and their proliferation being identical and independent of the specificities of the medium) offers a unique possibility to extend the laws established for autowave behaviour in an active medium to a broad class of media of a different physical nature. This was indeed the case when revolving vortices (reverberators) were discovered: they were predicted by theoreticians who analyzed mathematical models of propagation of excitation waves in the cardiac muscle, and were later experimentally produced in a chemical active medium. Still later reverberators were found in independent experiments with heart, with populations of slime mold amebas, and with chicken's retina.

Nowadays a transfer of ideas and results from one scientific discipline to another has become an effective working tool for research into autowaves. There is much to be gained by a consistent application of this principle. The results obtained in the studies of autowaves on the cardiac muscle, in the work on arrhythmia mechanisms and methods of controlling them are extremely important because they

directly address the life-and-death aspects of human existence. The organizing role of autowaves in morpho- and embryogenesis processes is not less interesting, as dealing with two central problems of biology; indeed, it is well known now that the propagating and "frozen" autowaves (the latter are also called dissipative structures) play a decisive role in shaping processes not only for *Dictyostelium discoideum* amebas but also for more complex organisms, even vertebrates.

Another pressing need arising in biology is the study of autowaves governing the propagation of epidemics, ecological invasions, and destabilization of biogeocenoses. The practical importance of solving the problems they entail is self-evident.

Cybernetics' Standpoint

Cybernetics Approach to Theoretical Biology

A. A. LYAPUNOV

Biology, as we know it, has accumulated vast amounts of empirical data concerning the description of structure of living organisms, their ensembles, and life-sustaining processes. In each biological discipline, the reigning standpoints and objectives dictate the way to systematize the relevant information. At the same time, the effort aimed at systematizing the biological data as a whole from a unified theoretical point of view is clearly inadequate. This situation is probably caused by the copiousness of the data, on one hand, and by insufficient theoretical understanding, on the other.

Nevertheless, some attempts are worth making at the moment. The fact is that cybernetics opens up new theoretical possibilities and contains a promise that fresh unifying concepts will arise in biology.

The aim of the physico-chemical approach to biology is to reveal the elementary life processes and to study them within the framework of the physico-chemical standpoint. The goal of the cybernetics approach to biology is to form a holistic understanding of life processes using the knowledge of the structure of organisms and the elementary life processes. A synthesis of these two approaches may, hopefully, lead to the birth of unified theoretical biology.

As a first step, we need to define the domain to be considered and to formulate clearly the problem and the basic concepts.

In the present paper we intend to outline a cybernetics approach to analyzing life phenomena.

1. Empirical natural sciences accumulate factual data and offer its primary systematization. The theoretical branch rearranges the data into a coherent whole and looks for general laws reigning in nature and revealed in the data. The mathematical branch constructs model objects obeying similar laws and studies their behaviour.

The completeness with which the basic laws of a field of knowledge have been revealed is found by comparing the functioning of these models with real systems.

This is how the experimental, theoretical, and mathematical branches of natural sciences are interrelated.

In the case of biology, the empirical branch is very well developed, the theoretical branch is much less so, while the mathematical branch appears to date as a collection of loosely related particular theories.

2. For the systematization of the empirical biological data in biology, it is necessary to work out a unified standpoint, equally essential for all biological disciplines. The biochemical, or bioenergetic, concept, based on treating the physico-chemical processes which make up the foundation of life, can serve as this unifying standpoint. Another possible approach is offered by cybernetics. This approach requires the study of control systems in living beings and of the control processes necessary to sustain life. In the future, these approaches will permit the construction of the mathematical models of life processes; a synthesis of the two will prove to be most fruitful achievement.

3. Specialized control processes constitute an essential feature of life-sustaining processes. The main characteristic of the former is that the transfer of small masses or small portions of energy results in processes which transfer or convert much greater amounts of energy or mass.

The purpose of cybernetics (or rather, control engineering) is to analyze control processes and the structure of control systems by mathematical tools, so that it is quite natural to make use of this science for studying the control of life-sustaining processes.

In what follows we shall operate with a system of exact concepts introduced by control engineering, namely, *information*, *control system*, *elementary act*, *signal*, and *communication channel.*

4. Control via information transfer constitutes a component of any life-sustaining activity; in fact, control can be said to constitute the characteristic attribute of life in the broad sense of the word. The possible counterargument that control is widely used in industry is groundless because machines are designed by people, i.e., by living beings endowed with conscience.

5. Let us attempt to give a definition of life proper. Note that so far biology was unable to define the terms "alive", "life", and "life-sustaining process". This situation does not involve any difficulties for the descriptive biology, but creates extreme complications for theoretical biology, and even more so, for mathematical biology.

6. We propose to choose a set of phenomena which is broader than that of phenomena of life, but one which is well defined, and also to take the set of the branches of knowledge which study this chosen set of phenomena. Making use of some accurately described attributes, we will try to single out from this set those which are identifiable as manifestations of life. At the same time, we shall define the set of biological disciplines.

7. We begin with considering distinct states of matter and those fields of natural science which study these states. A state of matter can be described if we choose spatial and temporal scales and a set of physico-chemical characteris-

tics. This set of characteristics must satisfy the condition of sufficient completeness. Unfortunately, it is hardly possible now to list the necessary characteristics. This list must include mass, total energy, free energy, chemical composition (in terms of elements, especially in terms of stable groups of atoms, or individual chemical compounds), and possibly the magnetic and electrical characteristics of bodies. Different combinations of the said characteristics may be necessary for particular problems. All these characteristics must be defined for a part of the analyzed substance within a randomly positioned sphere which is entirely buried in the substance to be analyzed. The law describing the distribution of positions of this sphere must be prescribed in advance. Very often the center of the sphere is supposed to have constant distribution density everywhere in the admissible domain.

8. We are mostly interested in the mean values and variances of the chosen characteristics. Let us identify the substances which are characterized by relatively low variances at a given mean value of the characteristic. We refer to these substances as homogeneous. Note that the homogeneity of a substance essentially depends on the diameter of the chosen spheres. The variance of characteristics increases with decreasing diameter in any substance.

9. Now we consider the variation of the characteristics of the material studied in time. We are interested in materials which differ from other materials by a higher stability of their characteristics as functions of time. Consequently, it is necessary to choose a unit time, and to study how the chosen characteristics vary within one unit of time.

Materials whose average characteristics remain almost constant in time as compared with those of other materials (having close values of the same characteristics) will be referred to as relatively stable.

10. In general, the stability increases with increasing diameter of the spheres used to determine the characteristics. If the fates of different parts of a material are random and mutually independent, it is possible, under some very general assumptions, to find the relation between geometric size and stability. Of interest are the cases in which the stability of large aggregations proves to be higher than predicted by the theory. The material is then said to have enhanced stability.

11. Two sorts of factors influence the stability of a substance. Stability may result from unusually favourable external conditions, such as preservation or thermostating. Such situations are of no interest here. Another type of sustaining the stability is traced back to the internal response of the substance to external factors, which tends to maintain the equilibrium. Response of this type is said to be preserving. Materials of interest for us are those which have preserving responses.

12. Preserving responses arise when the substance receives the information on the external factor, processes this information, and generates new information, namely, a physical system of signals which trigger an internal restructuring of this substance, such that the main characteristics of the substance are preserved.

13. Both the input and the output information are encoded in a finite number of discrete signals which are allowed to assume a finite number of distinct values. Each signal is realized either by a specific physical process or by a specific state of a material object.

Carriers of signals change in the course of data processing. Systems of signals of one type are thereby transformed from one code into another.

14. The data is processed by a device of discrete nature, called *control system*. A control system is composed of indi-

vidual elements connected by communication channels. Some of the elements act as inputs and some as outputs. The function of communication channels is to transmit signals. The elements receive, process, store, and yield signals. The device used to store the data is called the memory. In most cases data is stored either in cyclic combinations (loops) of elements and communication channels in which signals circulate or in elements which are capable of occupying several stable states and of going from one another in response to the input signals.

In general, the way in which an element processes the signal is dictated by the type of this element of control system and by the state which it occupies.

15. Information stored in the control system is encoded in the discrete states of a finite number of discrete components of this control system, so that each of these components occupies one of a finite number of allowed states; in other words, the information is stored as a text of finite length, written in an alphabet consisting of a finite number of symbols.

The way in which the incoming data is processed is essentially a function of the information stored in the memory of the control system.

16. The control system, whose function is to generate preserving responses to various external stimuli, receives information on these stimuli, splits it into components, and compares them with the information stored in the system. The output information is composed in correspondence with the results of this comparison. The flexibility of the control system depends, therefore, on the amount of information stored in the memory.

17. Hereafter we will be interested in a substance which is homogeneous only on a sufficiently large scale, is rela-

tively stable, has enhanced stability, and possesses a control system which generates preserving responses.

Now we need to analyze how information can be stored in such control systems.

18. External factors are classified by characteristic time. For instance, there are external factors due to the motion of surrounding bodies with a velocity of the order of several meters per second, external factors due to weather fluctuations, diurnal and seasonal external factors, and finally, perennial factors.

The response time of preserving response must be matched with the characteristic time of external factors. This constraint imposes certain conditions on the response time of control systems, for example, on the time of information retrieval from memory.

19. In general, the diversity of external factors is considerable. Responses are less diverse, because the same response is often a preserving one with respect to more than one type of stimulus; nevertheless, in some cases this diversity is also substantial. One immediate consequence is the large amount of stored information. Hence, the control system must have large data storage. We conclude that the control system is capable of responding to the multitude of external factors if its memory operates with a large number of material carriers of information symbols.

20. The environment thus imposes two types of requirements on the control system and its memory, namely, sufficiently short response time and storage of a large amount of data.

Obviously, it is not easy to meet these contradictory requirements simultaneously. The difficulties are partly alleviated by the fact that these requirements are to some extent anticorrelated.

The diversity of the fastest external factors (among those which cause preserving responses) is relatively poor. The

longer the characteristic time, the richer the spectrum of external factors.

We conclude that the requirements formulated above can be met by a set of control systems some of which are slower but have larger memory, while others are faster but have smaller memory. In reality this set of control systems will have dissimilar physical mechanisms of storing and transmitting the data, different anticorrelated ratios of computational speed and memory size, and different physical principles of operation.

21. Note that each response involves an actuator, or actuators, having certain power and mass. On the whole the efficiency of functioning is the higher, the greater the masses, power, and energy of the actuators. The concentration of energy stored in actuators is necessarily limited. Hence, to improve the efficiency of the whole, it is important that the control system has a relatively small volume.

The information carriers must, therefore, be very small.

22. Let us discuss in more detail the control systems which generate preserving responses and at the same time meet the severest constraints on the geometric size of the carriers of information symbols. The storage of data in the control system's memory must be extremely reliable, otherwise the information cannot maintain the stability of the whole. At the same time, structures formed by a small number of noninteracting molecules can never be stable, in view of, for example, thermal motions. Stable materials serving as information carriers can, therefore, be either macroscopic (in this case their stability is caused by statistic factors) or monomolecular, or crystalline, but in the last case the information carrier is the type of crystal lattice composed of identical periodically arranged unit cells. This mode of information storage entails very high redundancy, and thus cannot be economical in volume utilization.

23. The substance we single out is, therefore, bounded and homogeneous, relatively stable, has enhanced stability, produces preserving responses, and incorporates a control system which generates these responses and uses information encoded and stored in monomolecular carriers.

We refer to this substance as living matter.

In short, life can be defined as the highly stable state of a substance which generates preserving responses dictated by information encoded in the states of individual molecules.

Information Theory and Evolution

M. V. VOLKENSHTEIN

The concept of information appeared in physics in the context of developing the foundations of statistical mechanics, although the term itself was not yet used. The relation between entropy and the probability for a system to occupy a state, established by Boltzmann, implies the relation between entropy and the amount of information. Entropy is a quantitative measure of the lack of information about the system. The basic propositions of statistical mechanics are derivable from the canonical information theory developed by Shannon and some other scientists in the context of the problems of communication theory. The equivalence of entropy and the amount of information was first pointed out by Szilard; in fact, this equivalence indicates a simple conservation law: for a given probability distribution of state occupancy, the sum of microscopic information and entropy is constant and equal to the maximal obtainable information or to the maximal entropy of the system.

Obviously, both entropy and information must be expressed in the same units, such as bits or units of energy divided by temperature. Increased information entails decreased

entropy, and vice versa. Here both quantitites are treated microscopically.

The equivalence of information and entropy is no more surprising than the equivalence of mass and energy implied by Einstein formula

$$m = c^{-2}E,$$

where $c = 3 \times 10^{10}$ cm/s is the velocity of light; 1 erg is equivalent to a mass of 10^{-21} g. Likewise, 1 bit of information is equivalent to $k \ln 2 = 10^{-16}$ erg/K of entropy, which is a very small amount of entropy ($k = 1.38 \times 10^{-16}$ erg/K is Boltzmann's constant).

The message of this equivalence is that new information is obtained "at a price" of increased entropy (in a different part of the system). No information can be obtained about the state of an adiabatically isolated system. In other words, some energy must be dissipated. The minimum energy consumption per one bit of information obtained is $kT \ln 2$, where T is the absolute temperature.

We speak of obtaining information without seeking for the profound implications of this process. The capabilities of information receptors are very limited in the standard canonical information theory used for developing the foundations of statistical mechanics or for solving problems in communication systems. A receptor can only distinguish between distinct states and between letters in a message. This is an obvious advantage of the canonical theory. When solving a problem dealing with the number of telegrams that can be transmitted through a communication channel, the content of the messages is ignored.

Physics is based on receiving information, i.e. on measurements. Only quantities that are measurable in principle carry a physical meaning and contain information. We are justified in using the canonical theory when analyzing

measurements only as long as we disregard their consequences. These aspects were thoroughly analyzed by R. P. Poplavsky [1].

Using the canonical theory, Brillouin was able to solve a subtle physical problem concerning the functioning of the demon of Maxwell.

The canonical information theory is thus an inseparable part of physics. Nevertheless, this theory does not cover reception, memorizing, and generation of information. In fact, these are the processes that are essential for biology.

In his posthumous monograph [2], I. I. Shmalgauzen for the first time attempted to convert Darwin's work into a theory in terms of the canonical information theory. He introduced the feedforward and feedback channels through which the genetic and phenotypic information is transferred, and discussed the rules of encoding and transforming the biological information. This new language of the theory of evolution is substantive and has a pragmatic significance in that it further develops and clarifies its basic concepts. Suffice it to quote the following passage: "The entire mechanism of natural selection can be presented in terms of information theory as the transformation of feedback information, which is transmitted phenotypically at the level of the organization of individuals as complete systems, to the hereditary information which is transmitted at the molecular level of organization through chromosomes".

Shmalgauzen also pioneered in this work the argument that "the current information theory has no techniques available to it for evaluating the quality of information, although this factor is often of decisive importance in biology. When an organism receives information from the environment, first of all it evaluates this information from the standpoint of its quality...".

This statement is irrefutable. The quality, meaning, con-

tent, or value of information have indeed become the object of study in biophysics.

Let us accept the term "value of information". Obviously, this concept can be defined only in connection with the reception of information because a measure of this value is given by the consequences of the reception of this information by the organism. Hence, an analysis of the value of information must begin with an analysis of reception.

The reception of information, and hence, its storage, is a process which is in principle irreversible; it is realized when the initial state of the receptor is unstable and the receptor switches to a new, relatively stable state. The definition of the quality of information involves a concept of the level of reception. This concept is related, among other factors, to the amount of information stored earlier (the thesaurus of the receptor).

Reception signifies that information has been irreversibly memorized. Information can be lost (forgotten), but it cannot be channeled back.

As a result of the extremely nonequilibrium nature of the process of reception, triggered phenomena, similar to phase transitions, take place; such processes are especially important in biology. The processes are such that very small amounts of information cause substantial, macroscopic events. For instance, one bit of information carried by a change of traffic lights from red to green triggers changes in traffic flow.

In the case of reception and storing the incoming information, the equivalence of information to entropy is far from obvious. At the same time, these processes are evidently real physical phenomena calling for further analysis. In my opinion, the difficulties encountered in this field by thermodynamics are of principal nature, and follow from the difficulties in dealing with irreversible processes involving

long-term memory, i.e., processes with very long (practically infinite) relaxation time (relaxation time is the time necessary to reach equilibrium). What are entropy and thermodynamical probability in these conditions? Alas, the physics of such irreversible processes has not been developed yet, despite some substantive efforts.

This is also true for another phenomenon which is of utmost importance for biology, the generation of new information. The creation of new information is the act of memorizing the outcome of random selection. Phenomena of this type are abundant in evolution. Sexual reproduction is equivalent to storing the outcome of a random event, namely, the formation of a new genotype as a result of recombination of the parent genomes. This event is indeed random (and hence, somewhat free) because no law dictates that the offspring should be born to this particular pair of individuals.

Incidentally, the generation of new information by creative activities, such as writing poetry, also proceeds in the manner of making a random choice (i.e. free choice) to memory.

Here again we encounter an irreversible process which is difficult to interpret in terms of thermodynamics.

Information thus has two, and only two, aspects that directly concern physics. The first aspect is the amount of information in equilibrium; the second one is the value of information, directly related to the process of reception and memorizing. No physical theory of these processes has been developed so far. It is clear, nevertheless, that this is a job for physics, and solely physics.

Regardless of the future theory, we can accept, with reservations, a conditional definition of the value of information as the degree of its non-redundancy or independence [3]. Redundant or repeated information is of no value for the receptor. The protagonists of Jules Verne's *Captain Grant's*

Children successfully reconstruct almost the entire text of the message extracted from a bottle, even though quite a few letters are washed off. Hence, these letters were redundant; in contrast, non-redundant, irreplaceable letters have high value.

With this definition of the value of information, we come to a conclusion that in the course of biological development (ontogenesis and phylogenesis) the value of information, and hence, its irreplaceability, increase. The former factor is evidenced by the transformation of presumptive rudiments into determinative ones in the course of embryogenesis, and also by the phenomenon of recapitulation. The latter factor is found in the event in which new species arise from common ancestors as a result of biological divergence. Numerous examples could be added to these two. The essential feature is that the value of information changes in the manner of phase transition.

If evolution enhances the value of information, there are reasons to believe that a similar effect takes place at the molecular level. A conditional scale of the values of amino acid residues in proteins can be composed in terms of residue replaceability. Using this scale, it is possible to show that the total value of amino acid residues in cytochrome *c* was indeed increasing through the evolutionary tree both for mammals and for birds. This means that mutation-caused replacements substitute less valuable residues for more valuable ones. In fact, no such relationship was found in the case of hemoglobins: evolution resulted in random substitutions.

These results agree with Kimura's neutral evolution theory which holds that at the molecular level the evolution mostly proceeds in a neutral, random manner. Numerous replacements of nucleotides in DNA or of amino acid residues in proteins do not feel the pressure of natural selection which

acts at the phenotype level. Kimura's theory is well supported by evidence. Its physical meaning reduces to a non-single-valued, degenerate correspondence of the primary protein structure, which is genetically encoded, and the spatial structure which is responsible for the biological function of the protein. In spite of the statements of some scientists, the neutralism theory in no way stands in opposition to Darwin's theory.

Nevertheless, different proteins hehave quite dissimilarly. A more ancient and universal protein, the cytochrome *c*, is less subject to mutations than a younger protein, hemoglobin. This explains why the roughly manifested trend of increased irreplaceability of amino acid residues is observed for cytochrome *c* but not for hemoglobin. In this sense, the protein evolution goes "from Kimura to Darwin", from neutralism to selectionism.

It was shown that the evolutionary enhancement of protein value requires that there be a stock of residues with low value, i.e., with high replaceability.

The principle of evolutionary growth in the complexity of biological systems was discussed in the literature in recent years. The complexity concept needed a rigorous definition. Such a definition was given by Kolmogorov: the complexity of an object is the minimal number of binary digits, encoding the information on this object, sufficient for reproduction (decoding). In other words, the complexity is the length, measured in bits of information, of the shortest program generating the message about the object.

In order to ascertain that a given sequence of digits is complex (i.e., random), it is necessary to prove that no shorter program is possible for generating this sequence. This statement cannot be proved in view of Gödel's theorem, and the proof calls for a system of greater complexity.

We should emphasize at this point that science invariably

aims at discovering the minimal program which generates (explains) the set of facts available for analysis: this is the familiar Occam's razor. Thus, Newton's law of gravitation explains both the fall of an apple and the motion of planets. However, Gödel's theorem does not permit a proof of the minimality in terms of logic. This is why science is impossible without intuition. Mandelshtam used to say that the Schrödinger equation was the result of guess, not of inference.

The most complex systems in nature are individual living organisms, man's organism among them. Each living being is unique, and cannot be presented by a shorter program. In this sense, "nobody is replaceable". This statement holds also for man's creative output, the pieces of literature and art.

However, each organism is more than just an individual. It represents a kingdom, phylum, class, order, family, genus, and species. This is a very real hierarchy, and its discovery constituted one of the greatest events in the history of science. The complexity is obviously increasing from kingdom to species. Within each taxon, "nothing is irreplaceable": all representatives of a given species are interchangeable, and are described by the same minimal program.

Let us turn to evolution. Usually, although not always, complexity increases in the course of phylogenesis. For instance, the transition to the parasitic existence signifies simplification, not greater complexity.

The concept of complexity is relative. A bull's brain is a fantastically complex system for the biologist who needs hundreds and thousands of bits for its description, but a butcher needs at most 5 bits, since brain is merely one of about thirty edible parts of bull's body.

We have to deal with different levels of data reception, with the relativity in the value of information. We find that complexity is equivalent to irreplaceability, or to non-

redundancy at a given level of reception. What is irreplaceable, is complex. The impossibility of a further minimization of a program which generates a complex message signifies that the program is irreplaceable. Both the information value and complexity increase in the direction from kingdom to species and reach a maximum in the individual. Nevertheless, the concept of the value of information is richer than that of complexity. The complexity refers to an object as a whole, while the value is inherent in each individual element of the object. The complexity characterizes the structure, while the value represents the function as well.

Consider the evolutionary simplification, which occurs in the evolution of vertebrates too. In four families of deep-sea anglerfishes (*Caulophrynidae*, *Ceratidae*, *Neoceratidae*, *Linophrynidae*) the relations between sexes are very peculiar. The male, which is much smaller than the female fish (a *Ceratis holboelli* female is more than 1 m long, while a male may be as short as 15 mm!), penetrates the skin of the female, after which its jaws, eyes, and intestines undergo reduction, so that it ultimately transforms into an appendage producing the sperm. The simplification is indeed drastic, but its outcome in these specific ecological environments is the enhancement, not decrease, of the value.

The principle of value enhancement is independent of natural selection. Nevertheless, its formulation deliberately emphasizes the inherent directivity, or irreversibility, of biological evolution.

An increasing value entails an enhanced ability of a biological system to extract valuable information. This ability is especially well developed in higher animals whose sensory organs specialize in information selection. The frog responds only to moving insects, the bat operates its sonar and responds only to reflected signals, not to direct ones. The selection of valuable information forms the foundation of

man's creative activities. This selection requires no additional energy consumption, and one bit of information is obtained at a cost independent of its value.

Natural selection means that phenotypes are subjected to comparative evaluation in terms of a given ecological niche, i.e., it is a search for optimal value. The situation can be elucidated by an analogy to chess.

At the initial position a chess player selects from among 20 possible moves. In reality no one with even a minimum skill searches among all these moves ("all mutations") but analyzes at most five or six possibilities. The number of possible moves increases with each move, but the choice narrows down still more. Each move creates a new "ecological environment" on the chess board. The role of mutation is played by the opponent's move. Once a game of chess was directed into a certain path, it cannot be drastically redirected. The game is irreversible; the moves cannot be retracted. Here lies the analogy to evolution, which is invariably a one-way, or channelled process. Terrestrial vertebrates have four limbs because their ancestors, Late Devonian *Crossopterygii* bony fishes, had four corresponding fins.

Chess suggests another, more interesting analogy. According to Steinitz's theory, the game must follow the positional strategy, striving to accumulate small advantages. Once the advantages grew sufficiently large, the player was to seek a combinational, resolute path to victory. The nontriviality of this theory, which was supported by Lasker's detailed logical arguments, lies in the following feature: if the positional gains are not used for advantage at the right moment, they vanish. Lasker wrote: "The combinational and positional strategies of a chess master are complementary. A combination serves to invalidate false values, and the positional game is aimed at solidifying and utilizing the true values" [4].

Lasker regarded chess as a model of "life's struggle". He did not notice that chess offered a model of natural selection and struggle for survival: the accumulation of small advantages is similar to microevolution, and the transition to a combination is like macroevolution, or phase transition. One of the basic problems in evolution theory is the reducibility of macroevolution to microevolution. The above arguments are very similar to the concepts of idioadaptations and aromorphoses introduced by Severtsov [5].

The terminology used by chess players is in itself an indication of the analogy. Botvinnik wrote: "Euwe was able to adapt himself to a situation arising in a game... An analysis of 'adaptive evaluations' in a game of chess will lead to the rise of the perfect chess robot" [6].

The directivity of evolution is imposed by both exogeneous and endogeneous factors. The exogeneous factors are the ecosystem and natural selection. The endogeneous factors stem from the program of ontogenetic development incorporated in each organism; this program imposes rigid bounds on the evolutionary diversity. The problems of evolution are inseparable from those of ontogenesis, and the interrelation of ontogenesis and phylogenesis can, in fact must, be considered in the framework of information value concepts. The notion of the value, or irreplaceability of information is a fundamental one. Note that the "technology" of biological evolution differs from the man-made technology. We tend to construct machines from mutually replaceable parts, composing sets of spare parts. For any organism more perfect than a hydra or sponge, the decisive factor is irreplaceability at all levels, up to the immunological level in higher vertebrates. The rejection of "block technology" and "spare parts", giving up the capability of regeneration, is the price for the sophisticated holistic organization, for the well-developed nervous system.

References

1. Поплавский Р. П. Термодинамика информационных процессов. М.: Наука, 1981.
2. Шмальгаузен И. И. Кибернетические вопросы биологии. Новосибирск: Наука, 1968.
3. Волькенштейн М. В. Биофизика. М.: Наука, 1981.
4. Ласкер Э. Учебник шахматной игры. М.: *Физкультура и туризм*, 1937.
5. Северцов А. Н. Главные направления эволюционного процесса. М.: Изд-во МГУ, 1967.
6. Ботвинник М. М. От шахматиста к машине. М.: *Физкультура и спорт*, 1979.

Control Sciences and the Harvest

YU. M. SVIREZHEV

This article is an attempt to approach the problem from different angles, e.g., that of engineers and ecologists, and pose some questions which can hardly be answered in unambiguous terms.

Until recently the agriculturists did not need mathematics other than ordinary statistics and design of experiment. It is curious, however, but it were the needs of agriculture that gave an impetus to exploring these mathematical fields. Thus Ronald Fisher, one of the founders of today's statistics and experimental design theory, had closely cooperated for years with selectionists at Rothamstead experimental station in Britain.

Control engineering, optimization principles, and computer control were originally applied in manufacturing industries and greatly enhanced the productivity of labor. Agriculture was initially left out, probably for two reasons: (1)

unlike industrial processes, biological systems cannot be easily described in formal mathematical terms, and (2) owing to its ancient origin agriculture is more conservative and so tends to preserve its centuries-old practices. But the growing needs called for dramatic changes.

This was the case when mineral fertilizers were introduced in the middle of the 19th century. At that time J. Liebig approached the stepping up of agricultural production as a problem in engineering, and formulated a typical control-science-like principle of limiting factors. Known today as the "bottleneck" (critical path), this principle is widely applied to process control and economy management.

Agriculture Viewed by Engineering. Harvest Programming

An engineer may regard agriculture (in the narrow sense of the word, i.e., crop growing) as obtaining a product with the use of some mineral raw materials and solar energy with a certain efficiency. The principal technology is photosynthesis. The process is controlled by varying the input flow of the raw material; the output, the harvest, is maximized in actual environmental conditions by optimizing control. This, roughly, is a definition of the "harvest programming" approach.

A process cannot be controlled, however, unless its model is available. In our case a green plant or a vegetation population has to be modeled. Let us consider Rachko's model.

The growth of a hypothetical plant is described as the dynamics of the biomasses of its leaves, stalk, and roots. The exogenous variables (factors) are the photosynthetically active radiation (PAR), the air temperature, the water supply in the environment, the carbon dioxide content in the ambient air, and the concentration of mineral elements

(nitrogen, phosphorus, calcium, and sodium) in the soil. The internal variables are the biomasses of leaves, stalk, and roots and the concentration of nitrogen, phosphorus, calcium, and sodium inside the plant. In a very crude form the conceptual diagram of this model is shown in Fig. 13. The flows of substance and energy are represented as solid lines, thick and thin, respectively, and control data transmission links, as dashed lines.

When carbon dioxide and nutrients are available and the temperature is right, the PAR-initiated photosynthesis

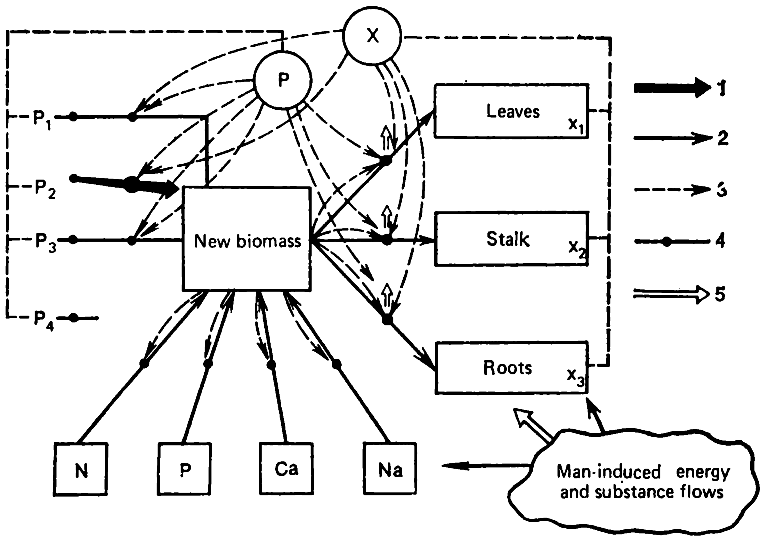


Fig. 13. Conceptual diagram of a plant model

$p_1 = p_4$ are the CO_2 concentration, PAR, water potential, and temperature, respectively; P is a vector with components $p_1 = p_4$; $x_1 = x_3$ are the biomasses of leaves, stalk, and roots, respectively; X is a vector with components $x_1 = x_3$; *1*, *2*—energy and substance flows; *3*—data flow; *4*—flow regulator; *5*—respiration

produces new organic substances which are distributed in all organs of the plant. Simultaneously the energy for sustaining the life processes in the plant (such as the transport of the substances, biochemical processes, etc.) is released through the oxidation of these substances in respiration. The rate of these processes is dictated by the biomasses and geometry of the plant organs and by the exogenous variables. Besides, the plant has its own control mechanisms such as stomatal transpiration and distribution of the assimilants. Many of these mechanisms remain little explored and so the model loop is closed by using either empirical functions or general biological considerations which are formulated as some maximum principle such as adaptation. On the other hand, the dependence of photosynthesis on PAR, on availability of water, and on the concentration of nutrients has been thoroughly explored and can be readily integrated into the model.

Many variables and functions in the model have specific values only for specific plants. This is especially important in determining the geometric characteristics of an individual plant or a population. Thus the PAR distribution is dependent on the sowing geometry, i.e., a population variable, more than on the plant geometry.

The choice of specific values is the stage of model identification at which it is adjusted for controlling a specific crop. At subsequent stages the optimal control of the agricultural system is sought by varying the dynamics of watering, fertilization, etc. under specified environmental conditions beyond human control, such as ambient temperature and rainfall.

This approach has been used in the Computing Center of the USSR Academy of Sciences by R. Saidulloev and A. M. Tarko who developed a cotton growth model. Thus, numerous computer experiments suggest that periodic water-

ing results in better harvests than continuous watering does.

Now, a question may arise, why bother with a model which cannot recognize all the factors when an optimal combination of control parameters can be obtained by experimental design? First, every experimental run would require an inadmissibly large surface and so would be costly and take too much time. Second, in experiment the exogenous conditions could not be monitored as closely as, for instance, in petrochemical synthesis where the response follows in a matter of seconds and the entire process is observable. Simulation methods are therefore preferable.

In the Netherlands models of wheat and corn growth have been experimentally tested. In the USSR harvest programming is the subject of vigorous research by E. P. Galyamin, R. A. Poluektov, Yu. K. Ross, and O. D. Sidorenko.

Agricultural Viewed by an Ecologist. Monoculture or Agrocenosis?

An approach in which agriculture is viewed as a kind of manufacturing industry, the plant as a kind of machine, and the harvest control as an engineering task is legitimate at a certain stage because it results in a sharp increase of farming production. However, a price should be paid for this increase. The production cost estimated in terms of total energy and mineral inputs expressed in energy units per ton of wheat has increased 50-fold during the last 100 years.

In this sense the highly industrialized US agriculture is 250 times costlier than the traditional agriculture of South-East Asia. Programmed harvesting on a larger scale would be still more expensive because a price would have

to be paid for both the indispensible information on the system state and for control itself, i.e., for maintaining the system at the computed optimal level.

At this point the desire to obtain maximal productivity is in conflict with the maximal stability requirement made by nature to every bilogical community, be it population or biocenosis.

One ecological indicator of the community's stability is its variety. This is essentially a measure of the amount of information describing the community. The stability in face of environmental variations increases with the number of species having different characteristics. On the other hand, the productivity of a community is maximized when all the individual characteristics are made to approach some optimal value. In this way, however, the variety is reduced. Monoculture is ideally optimal but also absolutely unstable because there is no variety in it. It is human control that keeps monoculture stable.

The evolution of natural communities increases their variety. The community pays for it by increased energy dissipation. Any exploitation such as collection of a harvest and removal of some biomass from the community reduces the dissipation, and, consequently, the stability.

So, harvesting should be discontinued if stability is to be maximized and if it provides a maximal harvest the community is absolutely unstable. From this point of view the agrotechnology of high yield crops is but stabilization of the unstable monoculture population.

A compromise should probably be sought whereby monoculture is replaced by an agrocenosis (agroecosystem), a man-made community whose structure would be fairly similar to that of natural communities and whose stability would be largely maintained by inherent ecological regulatory mechanisms rather than a flow of man-supplied energy.

Development of ecologically optimal agricultural structures is today on the agenda of mankind.

Let us consider a modeled case study.

Theory of Trophic Chains. Harvest versus Stability

Let us start with some statistics. According to various estimates, about one third of the entire US harvest is lost

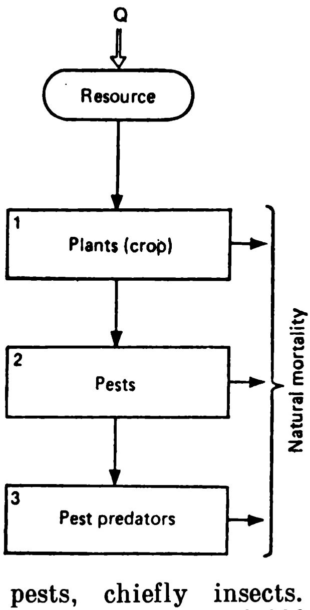


Fig. 14. Trophic chain of an agro-ecosystem
Q—resource arrival; *1-3*—chain levels

to pests, chiefly insects. The direct pest control costs amount to about 2,000,000 dollars annually. What are the environmental consequences of this combat?

Figure 14 shows the trophic chain of any crop. The new trophic level is that of pests, such as the cotton-worms; it is followed by the parasites or predators of these pests, such as various ichneumon flies. The resources are mineral fertilizers Q. The harvest would seem to increase with Q as

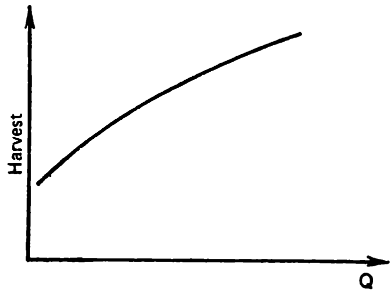


Fig. 15. Harvest as a typical function of fertilization

shown in Fig. 15. However, larger Q do not necessarily improve the harvest. The trophic chains are found to be discrete, or resource-quantized. Indeed, there are critical values Q_1^*, Q_2^*, Q_3^*, etc. such that if $Q < Q_1^*$, then only a chain of length *1* is stable; if $Q_1^* < Q < Q_2^*$, of length *2*; if $Q_2^* < Q < Q_3^*$, of length *3*, etc. (Fig. 16). In the first case the agroecosystem consists of plants alone, the amount of insect pests causing a negligible damage to the biomass of the useful species. Increased fertilization in this interval naturally increases the vegetation biomass, or the harvest.

However, as soon as Q exceeds Q_1^*, the chain length is equal to *2* and includes pests as well as the crops. Further increase of fertilization results in a dramatic increase in the amount of pests. The real yield falls because the increased yield maintains an increased amount of pests, Fig. 17. This situation continues until Q exceeds Q_2^*. Then the chain length is *3* and pest predators grow in number and suppress the pest population, thus improving the harvest,

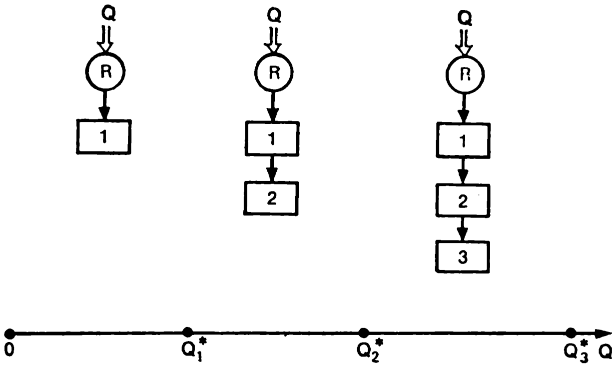


Fig. 16. Length of the trophic chain as a function of resource arrival
R—resource; *1-3*— levels of the trophic chain

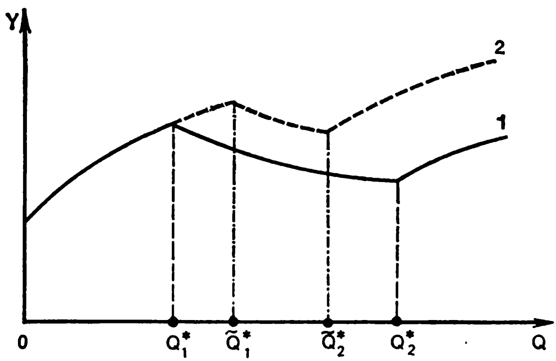


Fig. 17. Income from real harvest as a function of fertilization
1—without chemical or biological pest control methods; *2*—with the use of these methods; $\tilde{Q}_1^*$ and $\tilde{Q}_2^*$—critical boundaries

In effect, the dependence of the harvest on fertilization is not as straight forward as might seem at first glance. Highly productive monoculture seems to be an ideal but what actually realizes in nature is an agroecosystem, a biological community of many populations; the structure complexity increases with the increase in the energy and resource input flux. If nature has "a goal", then it is in conflict with human goals.

The harvest can be increased either by moving Q_1^* towards higher Q or by decreasing Q_2^*. In the former case the death rate of the pests has to be increased, for instance by using pesticides. In the latter case, the biological method of pest control is employed whereby pest predators are nurtured at special "farms" and set loose on the fields. Inevitably, these approaches require both energy and resources for creation and maintenance of a new stable community structure.

Agroecosystems Analyzed Ecoenergetically

The study of energy flows in ecosystems is a major method of ecological research which is obviously valuable in analyzing agricultural systems.

In developed Western economies energy studies of agroecosystems were triggered by the energy crisis of the 1970s. In this approach an agricultural system is treated as a system transforming an energy input into an energy output. The transformation efficiency which is the ratio of the resource inflow to the farm product is now widely used in comparative analysis of various agricultural sectors and entire agroecosystems.

The input flow of man-supplied energy is made up of direct and indirect energy inputs. The former are fuel for fieldwork, power and fossil fuel for heating the greenhouses and

farms, for drying grain, transportation, etc. The latter are mineral fertilizers and pesticides, installations and machinery, irrigation, amelioration, and other infrastructure costs (indirect energy inputs are also expressed in energy units).

The transformation efficiency varies widely from sector to sector. Thus its maximum in crop farming is 0.3 (recall that the solar energy is neglected); in livestock breeding it may be as high as 5 and in fowl farms, 10. This signifies that while one crop product unit costs 0.2 to 0.3 artificial energy units, in fowl farms it costs 10 units. For agriculture as a whole this index ranges from 1.5 to 3. In particular, it was 1.45 in France in 1970 and 2.9 in England in 1968.

This index can be reduced in two ways. One is a more efficient utilization of the resource influx, e.g., replacement of gasoline by diesel fuel, reduced tilling, etc. In 1973-1983 the energy consumption in the US farms has been reduced in this way by 17 per cent.

The other approach is the utilization of wastes such as straw and manure as energy sources and in fertilizer production. The EEC countries intended to increase the utilization of biomass for energy to 2.5-3 per cent of the total energy consumption (equivalent to 30 to 40 million tons of oil) by 1985 and to 7.5 to 10 per cent by the year 2000.

The energy consumption analysis may provide an estimate of new technologies and their characteristic energy flows.

* * *

To summarize, since agriculture is a complex large-scale system which may behave in a counter-intuitive way, simple solutions will hardly work. Nevertheless, their analysis by systems research techniques in the light of general ecological principles may prove useful.

II. The Complexity of Living Systems

Integrity of Life

On Systematic and Integral Nature of Man

V. G. AFANASYEV

Man is the "center" or "focus" of any social system. But what is the essence, or nature, of man himself? Is he an "element" of social formations or is he a complex, multifaceted system himself?

Back in the last century Karl Marx and Friedrich Engels rejected the cult of an abstract man, man in general, man outside human history. In their eyes man was part of a historically specific social entity such as a social formation or social alliance, e.g., class or nation. Man is always a link in the system of social relations. Marx wrote: "But the human essence is no abstraction inherent in each single individual. In its reality it is the ensemble of social relations" [1].

This does not imply denial of the biological in man. The social in man has not emerged and developed "overnight" or from nothing. It developed from certain biological features. Even now when man is clearly a social being, he also remains a biological being. Man is a biosocial system.

Biologically, man is a representative of the phylum of Chordata, the subphylum of Vertebrata, the class of Mammals, the order of Primata, and the family of Hominidae. As a biological being he is a mobile, self-controlled integral system. In Pavlov's words an organism is "a highly self-regulating, self-maintaining, restoring, correcting, and even

self-perfecting system" [2]. In this biological sense, man's components are cells, tissues, organs, and systems of organs which perform specific functions in the organism.

Biologically man changes much slower than socially. *Homo sapiens* is believed to exist for 40,000 to 50,000 years. Man's biology has no noticeably changed over this enormous period in the history of human society. His brain has not expanded, his heart pumps blood where it used to and the blood flow has not increased much. The senses and chiefly emotions remain generally as they were millenia ago. What changes fast is man's social nature. The personality of a slave and a slave-owner, the serf and the feudal lord, the worker and the bourgeois, and, finally, the socialist personality are the nodal points in the human social history from slavery through feudalism through capitalism to socialism covering "mere" several thousand years.

The biological factor is not, however, decisive. No doubt that the biological or the hereditary-biological traits have a significant role to play in the development of social and psychological qualities in man, but this role is not and cannot be fatalistic. The biological is merely a prerequisite for the making of man and for the development of his qualities, characteristics, and abilities, all shaped by social factors.

Man is a component of a multitude of systems. He is a member of his family and working team, of his class, and of his nation; he is a citizen of a certain country. He is a component of economic, political, and cultural systems. It is these systems rather than man as an individual that shape the social qualities. The decisive role in the formation of social qualities is played by the working, or productive activity. Engels noted that in a sense work created man. Work is embodied in the organization of a human body. A man is a man not because he consists of organs, tissues,

and cells, breathes with his lungs, and his children feed on mother's milk but because he is capable of working, thinking, and speaking, making tools with which he changes his environment, or nature, and in his working activities he enters into social relationships with other human beings.

What is more, many biological (anatomical and physiological) features of man such as the vertical gait, the shape of his skull, and the structure of his face result from his social life. The biological and social are inseparable in man but the human proper has social origins. "... the essence of a personality is not", as Marx said, "its abstract physical character, but its *social quality...*" [1].

A personality is described by its social, rather than biological qualities. It embodies certain social functions but in performing them it displays its own features such as the character, will, interests, needs, intelligence, knowledge, consciousness and self-consciousness, value orientation, and Weltanschauung.

Therefore, psychological features such as the character, temperament, will, sentiments, reason, habits, desires, etc. are inevitable components of the personality [3]. They show the way in which a person performs his social functions (role), what his physical and creative potential are, what is lacking in this personality for acting more effectively, whether the personality outgrew the framework of his functions, and whether a person should be used for performing a more sophisticated and important role.

Man acquires human characteristics in the course of his life, activity, learning, and work in a world transformed by numerous human generations, rather than he has them since his birth.

The behaviour of animals and their interaction with the environment are known to be programmed chiefly by the genetic information which is transmitted from generation to

generation. The living nature has not done much to assist the exchange of information acquired during the lifetime, except for the direct imitation, chiefly by the younger generation, and for a very primitive exchange of signals warning of danger or any other change in the environment. The social life makes quite different requirements to the information exchange. Social, rather than hereditary information, is of decisive importance. Superindividual acquisition, storage, and transmission of data from generation to generation (vertical data flows) and data exchange within one generation (horizontal data flows) guide the behavior of an individual.

"*Homo sapiens* is unique in that, in contrast to animals, this species has, in addition to a genetic program, a consciousness-generated program which dictates his evolution in every subsequent generation. This additional program can be referred to as the social heritage programs" [4].

This social heritage is, above all, the information embodied in working tools and other objects of this second nature, and stored in documents (books, newspapers, magazines, archives, etc.), works of art, including fiction, and in oral form. Because it inherits the achievements of production and socio-political and spiritual life of earlier generations, every new generation does not have to start everything anew both in cognition and in practice.

The decisive factor in the making of man, his qualities, characteristics, and abilities is the environment comprising things and events. This environment makes man what he is. Man, however, cannot act on his own in this world.

Man interacts with the world through relationships with other people, those who still are and those who are no more on the "world scene". The more sophisticated man's relationships with the world and other people, the richer his inner world and the more varied his activities.

Social, above all, economic relations and communication

with other people (direct with the contemporaries and indirect, through production, socio-political, and spiritual experience, stored in social information, with earlier generations) are the decisive personality-shaping factors. Marx and Engels wrote: "Hence it certainly follows that the development of an individual is determined by the development of all the others with whom he is directly or indirectly associated, and that the different generations of individuals entering into relation with one another are connected with one another, that the physical existence of the later generations inherits the productive forces and forms of intercourse accumulated by their predecessors, their own mutual relations being determined thereby. In short, it is clear that development takes place and that the history of a single individual cannot possibly be separated from the history of preceding or contemporary individuals but is determined by this history" [1].

Individual development from birth to death makes a personality human, in that it shapes those specifically human features that have been acquired by *Homo sapiens* in the course of the socio-historic evolution, and contributes to further expansion and sophistication of these qualities.

In effect, man is a social being, while the natural, or biological, features in him are only prerequisities for the realization of his social essence. This essence is dictated, first of all, by the social environment, the society where man lives and develops. The environment shapes his activities, features, and qualities.

These social (in a broad sense) and psychological features combined with biological qualities are the components of a personality as an integral system*. The overriding compo-

* Jan Szczepanski, the Polish sociologist, refers to these components as biogenic, psychogenic, and sociogenic; their mutual adaptation and conjugation make a personality.

nents are the economic qualities and the economic activities.

The specific interaction of these components creates the personality structure and the manifestation of these features and qualities in one's activities. In their unity, interaction, functioning, coordination and subordination these components add up to a personality as an entity, an integral system.

Man is thus a specific integral unit. Marx wrote: "Man, much as he may therefore be a *particular* individual (and it is precisely his particularity which makes him an individual and a real *individual* social being), is just as much the *totality...* as a totality of human manifestations of life" [1].

The wholeness of a personality is thus seen as the unity of various activities in his life, each being but a specific expression of a certain social relationship, a product of a social group. In its totality, or unity, life is the product and expression of the totality and variety of social relationships that tie the personality with other people. In this sense, the essence of a personality is a condensation of social relationships.

Man is also a replica or a condensation of the entire objectively existing world in all the variety of its manifestations. Man organically combines all laws of existence, mechanical, physical, chemical, biological, and social, the latter being dominant.

"Man's nature is a system of two subsystems, the organism and the personality, which are closely intertwined and influence each other. The unity of these subsystems is provided by the activity of the central nervous system, notably, the brain" [5].

The basic factor of wholeness and the systemic nature of man is his economic life. Another, subjective, mechanism of wholeness is his consciousness and self-consciousness, his control of himself, and language as a communication tool.

The collective, or systemic, nature of the economic life and work, consciousness and language, should be emphasized.

A specific personality has been seen to be a product of the social environment, of the social system. But then, why is there such a variety of human individualities in the same environment, the same society; why does a personality not acquire all the traits of the social environment to the same degree?

First, this environment is inhomogeneous. It always incorporates the core of today, remnants of the past, and nuclei of the future. Remnants of the old capitalist society continue to exist in the socialist society during the entire period of evolution to a communist society. The inhomogeneous environment acts on man in different, probably opposing, directions. Even though the decisive influence is exerted by the prevailing social relationships, man may be effected by relationships of the past and so develop qualities incompatible with the requirements of the society. This is one of the causes of the survivals of the past in the behavior and consciousness of man in the socialist society. With the triumph of new economic relationships, full economic equality, and social uniformity this factor will be eliminated.

No society or social environment where a personality lives and develops is insulated from other societies having their own socio-economic systems and cultures. Thus, today the socialist and capitalist societies coexist. The mass media enhance penetration of bourgeois ideas incompatible with the socialist world. The policy makers and ideologists of the bourgeois world do their utmost to revive bourgeois prejudices and habits in the members of the socialist society. This is another reason why the activities and mentality of some individuals are incompatible with the demands of the society.

There is, however, more to the variety of personalities than the difference between people of advanced and back-

ward views. Among either we can find different characters, inclinations, and tastes.

The most important cause of the variety is that every individuality is also shaped in the micro-environment of the family, school, by the workmates, etc. This micro-environment is a sort of interface where the economic and social relations and the spiritual life of the society are modified. The variety of the empirical circumstances which combine into a micro-environment is infinite; similar (in terms of the general social environment) personalities therefore show infinite variations and shades which cannot be explained out of the context of these empirical circumstances. If the micro-environment fits the societal environment and "works" in the same direction, then the personality acquires the features and relationships of the larger environment, and becomes their representative, adherent, and defender. If, however, the micro-environment for some reasons (remnants of the past, backward or misled people) "acts" in a direction opposing that of the society momentum, then the personality acquires features which are in contradiction with the social needs.

In socialist countries the means of production are owned by the people, the chief feature of human relations is mutual help, and the prevailing ideology is Marxism-Leninism. This medium in itself instills high social, moral, and intellectual qualities in a personality. But a specific personality may work among people who failed to develop friendly and comradely relationships or live in a family whose mentality is that of private owners and whose members are religious or act unethically. This immediate environment acts as a barrier between the personality and the society at large [6].

For these reasons the empirical circumstances of the life of a specific personality have to be thoroughly studied; the

micro-environment may have to be changed and made to work in unison with the larger social environment.

Man creates society by his labor, political activity, will, and reason, and the impact of his actions increases with social progress.

All people cannot be equally active; the degree of participation in the life of a society does not depend exclusively on the empirical circumstances, or the micro-environment alone; it is also a function of the hereditary features, the anatomophysiological, and psychological properties inherited from the ancestors, of personal experience, of education, and of intellectual and other qualities. The personality does not merely reflect the impact of the social environment but makes a selection among the incoming information according to his interests, needs, and objectives.

In short, the specific micro-environment, the specific historical experience taking an impact on the personality's character, the specific hereditary abilities, the degree of participation, and selection of the knowledge incoming from the society and micro-environment are the reasons why different personalities do not necessarily acquire all the qualities of the social whole or to the same degree. These reasons also explain the difference between personalities in behavioral patterns and in combinations of these patterns. These differences are thus both in the list of components and in the ranking of components.

A personality as an integral system is dynamic. It changes as the society, or social environment, does. Some features in the personalities behavior wither, some develop and consolidate, and some are acquired anew as the personality develops. Those features are shed first of all that were generated by the conditions of the bygone years and those are acquired and consolidate that fit the new society and new historical conditions. Thus, in the construction of socialist and com-

munist societies the features of a personality of the capitalist society wither away and those of a personality of a communist society are acquired.

Every personality is an integrity in that its manifestations are intertwined rather than isolated and add up to a human individuality as a separate, relatively independent unit. The wholeness and strength of links between manifestations of the personality and different in different historical conditions and depend, in a final analysis, on the social whole (such as formation or class) of which they are members. As society progresses, the incomplete disharmonic wholeness torn apart by conflicts, for which the society of antagonistic classes is to blame, will be gradually replaced by a truly harmonic wholeness of a truly free personality. This wholeness will be complete under communism, the highest type of social wholeness.

References

1. Karl Marx, Friedrich Engels. Collected Works, Progress Publishers, Moscow, 1975, 1976, Vol. 3, 5.
2. Павлов И. П. Полное собрание сочинений. М.: Изд-во АН СССР, 1951, т. 3, кн. 2.
3. Ковалев А. Г. Психология личности. 3-е изд. М.: Просвещение, 1970.
   Ковалев А. Г. Коллектив и социально-психологические проблемы руководства. М.: Политиздат, 1978.
4. Дубинин Н. П. Философские и социальные аспекты генетики человека. Журн. *Вопросы философии*, 1971, № 1.
5. Проблемы системного подхода в психиатрии. Рига: Научн. общество невропатологов, психиатров и нейрохирургов ЛатвССР, 1977.
6. Смирнов Г. Л. Советский человек. М.: Политиздат, 1980.

The Contribution of Psychology to Systems Research of Man

B. F. LOMOV

As the revolution in science and technology gains speed, the sciences, as well as the humanities, place an ever increasing emphasis on man and tend to joint their efforts in comprehensive studies of him. Psychologists stand much to gain from this integration in that they may acquire new tools for studying man as a multifaceted phenomenon, possibly in cooperation with researchers in other fields.

Although science of man relies to an ever growing extent on systems research techniques, this unique species whose life is a unity of natural and social laws is worthy of specific research tools.

As noted years ago by B.G. Ananyev and other outstanding Soviet psychologists, the basic social and natural sciences and application fields such as medicine, pedagogy, and technology may significantly contribute to studies of man.

In social sciences man is the most important component of any social system as the universal embodiment of the social quality, the main productive force, the protagonist of history, the personality, and the chief actor of the education process.

Natural sciences study man, *Homo sapiens*, as a product of biological evolution, as a genetically programmed individual with his own inherent variation range, as an organism which is a component of the environment, and in many other aspects and dimensions.

In medicine, man is the chief object of research and practice whose health must be maintained and diseases treated in an increasingly complicated natural and man-made envi-

ronments. Pedagogy looks for better ways to train and educate man as a useful member of society. Psychologists work to make the training more effective and set up a psychological service in shools. Technology strives to adapt monitoring, communication, and control systems to man's potential and to develop tools which would take over some human functions in various processes.

In effect, the need in accurate and comprehensive knowledge of man, his potential, his features, and laws of nature dictating his making, results from the very logic of scientific progress. What is equally important, better knowledge of man is indispensible in many industries if the productivity is to be stepped up, new technology introduced, the performance of the economy improved, and education and health services made more sophisticated.

Economists, engineers, production managers, educators, physicians, and propagandists are increasingly aware of the need to recognize and put the human factors to efficient use. Unfortunately, some fields of human research are lagging and some are in pitiable state. Thus, anthropology, literally science of man, has failed to enter into a dialog with other disciplines or make a worthwhile contribution to comprehensive studies of man. Meanwhile, if many large problems of the future are to be resolved, sciences of man are no less important than sciences of nature or of society.

Every researcher of man may have to look for data and tools in a related field. But he may be disappointed because the field he turns to is not so well-advanced. Thus psychologists frequently need the aid from genetics, human physiology, or applied sociology but do not find the desired data in the mountains of the literature. This may very well be true of biologists and sociologists who hope to draw on psychological findings. (I do not wish to settle the scores but merely state the facts as I see them.)

The necessity of using a systems approach in studies of man and in "ranking" the relevant knowledge is thus obvious. The body of fairly reliable knowledge of man in various sciences is rather impressive but a complete or logically consistent picture cannot be pieced together. What emerges thus far is an unbalanced mosaic with large "white spots". Isles of knowledge are separated by wide and deep gulfs of ignorance which tend to attract the peddlers of pseudoscience.

In the USSR V.M. Bekhterev who made a remarkable contribution to science of man called for a comprehensive approach when psychology was at its formative stage. Later B.G. Ananyev and many other researchers, achieved a significant progress along this line.

Scientific findings concerning man have to be merged in many, occasionally unexpected fields. A recent conference on engineering psychology discussed, in particular, the legal aspects of a human error in controlling advanced man-machine processes and found that certain regulations on inadvertent transgression of law were outdated. In cooperation with the engineers and managers the psychologists have to make a good job of professional orientation, for only few are capable of, for instance, flying airplanes or flight control.

Immanuil Kant was awed by two phenomena, the starry sky and the moral law inside man. I would add another magnificient phenomenon, the making of man.

Psychology has still, much to do in this field. Nevertheless, it already attracts new young talents; furthermore, social and natural scientists, engineers, and medical researchers improve their performance when their studies have a psycological dimension.

According to Jean Piaget, the eminent psychologist of this century, psychology is continuously at the crossroads between sociology and physiology. This uncomfortable posi-

tion offers, however, an advantage in that psychology tends to act as the interface of natural and social sciences, at least as far as studies of man are concerned.

Today man is studied by a ramified and expanding set of disciplines and lines of research. The differentiation of sciences of man, as of any other sciences, is generally a legitimate and desirable process. Every discipline stores its own kind of data. Each, however, is concerned with a specific part or aspect of the object or phenomenon and may lose sight of the entity. This is especially true of sciences of man. What should be constantly remembered is that genetic or physiological, psychological or sociological findings increase the knowledge of the same object, man as an entity. Indeed, the human organism or its parts such as the head, arms, or heart do not have special compartments responsible for materializing what the various sciences have discovered. Man and his organs and features are integrated in multifarious links and relationships with reality but he lives and acts as an entity. In two pages of his "Capital" Karl Marx describes the involvement of "the natural forces of man's body" (arms, legs, head, and fingers) in the process of labor; psychological properties such as "the workman's will... in steady consonance with his purpose. This means close attention..." and, finally, the ability to foresee the result of labor: "... the architect raises his structure in his imagination before he erects it in reality."

In my view, integration of knowledge from various sciences, natural and social, basic and applied, becomes a burning need.

Man as an object of scientific research is a most complicated system and his features and qualities are as various as his linksand relationships with the environment.

According to the philosophers, there are three kinds of qualities: structural, or dictated by the structure of the

object; functional, or following from the functions of the object; and systemic, or attributable to the fact that the object is part of a system.

Sciences of man study all the three kinds. On the other hand, where the specific features of these three kinds are not understood, serious errors occur and research may find itself in a cul-de-sac. This was the case of phrenology which tried to trace the psychological properties of man to the structure of his brain allegedly dictated by the skull shape. This is also the case of the attempts to relate the temper, character, and even Weltanschauung with the shape of the body or its various organs.

The relation of human qualities and innate specifics of organisms is not a simple matter and at this point we do not know for sure how to study or systematize these relations.

Functional psychological features of an individual may probably be classified into a pyramide of first-, second-, and higher-order characteristics. This remains, however, a rather general idea; besides, such classification can hardly be made by psychology alone without cooperation with human biology as a whole, i.e., physiology, genetics, etc., and with social sciences.

Systems properties, discovered by Karl Marx, are most complicated qualitative features. This discovery was thoroughly analyzed by V.P. Kuzmin in his book. "The Systems Principle in Karl Marx's Theory and Methodology". Being integral, these qualities cannot be observed directly and singled out unless those systems where man is incorporated and whose laws he abides by are analyzed.

In sciences of man two such systems are obvious, "man and society" and "man and environment". There would be no need in proving here that the basic relationships between man and the world are those which make him an element of the

social system. Rather, a reminder is often that man is a natural being as well as a social phenomenon.

Before Karl Marx, society was usually regarded as a stochastic product of individual activities. Objective laws of social evolution, if mentioned at all, were treated either idealistically or mechanistically. For the first time in the history of science Marx viewed the evolution of human society as an objective process. That was why Engels and Lenin compared Marx's contribution to social sciences with that of Charles Darwin to biology.

Marxism has developed a consistent theory of social relationships. For the purposes of this discussion one point in it is important. Some researchers regard social relationships as a thing outside the specific people, a force exogenous for people. For an individual, however, society is not merely an environment. His relations with society are not those of an organism with the environment. Therefore finding the mechanism by which man is integrated into the system of social relationships as an active subject would be a scientific breakthrough in understanding, in particular, his behavior.

In this context man should be regarded as the main component of any social system and a representative of the systemic quality of the society.

Social sciences are hardly capable of assessing on their own the social qualities of man as products of his being part of society. In my view, psychological sciences, notably social, historical, and pedagogical sciences, ethical psychology, and psychology of personality may provide indispensible help in this research.

A uniform treatment and ranking of human properties, from structural to systemic, is out of the question unless various sciences join their efforts. Reaching this goal would, I believe, be as significant for sciences of man as the periodic table is for chemistry.

Research of relationships between man an the environment would be very important for the analysis of his systemic qualities. His very origin makes it impossible for man to shed his animal-like characteristics. In his theory of historical development of society Karl Marx noted that man was a corporeal, live, sensious being full of natural forces.

But what are the natural forces and the physical organization of individuals? These questions are chiefly for natural sciences to answer. Here, as in social sciences, various lines of research may be explored because man's relationships with nature are as complicated as those with society.

For a long time the emphasis in studying this system was placed on the structure and functions of the human organism, or in the words of V.I. Vernadsky, the organisms-type organization of the living matter was singled out. But, according to Vernadsky, there are at least four levels of this organization: organism, population and species, biocenosis, and biosphere. The levels of the population and species and of the biocenosis have been given much less attention than the organism level. The relations of man, mankind, and the biosphere received still less attention.

I would not even try to classify the levels and aspects of the man-nature links. What is certain is that they are multi-dimensional and that various ranks of human features such as structural, functional and systemic are involved in man's relationships with nature.

The relationship between social and biologial characteristics in man cannot be the same on all levels of human life, at all stages of human development, or in phylo- and ontogeny.

Although there is a general consensus that man's nature is the product of history and that the biological laws in the evolution of man act indirectly as social laws, these formulations have not been presented as rigorous scientific findings.

The so-called biosocial problem is still discussed in very abstract terms. The extreme complexity of the problem is aggravated by loose statements of specific tasks, the infant stage of many disciplines, etc.

Psychology which might significantly contribute to this and related fields is largely underestimated. True, this field is now in vogue but what I mean is that the essentially psychological problems in evolution of sciences are not necessarily recognized as such and the approaches are not very sound. Many, if not most fields in the psychological science have to be explored by using the data of both natural and social sciences.

In this sense, I believe, the need in a comprehensive approach to the personality becomes obvious. The personality is a central concept in psychology. The findings in this field are helpful to sciences and technologies as well as to the humanities.

The features of a personality are also systemic. Unlike some bourgeois psychologists who derive the social from the psychological (societal features from those of small groups and these from the features of individuals), Marxism asserts that the understanding of society gives an insight into a personality. The features of a personality depend on its social identity. The emotional pattern of individual is understood in the context of the multidimensional dynamic space of social relations where he lives; in effect, its life in society has to be visualized. In studying its emotions numerous questions have to be answered such as what are the motivating forces of the personality's activities? In whose interests does it act? What is the social significance of its behavior?

On the whole, the study of the personality and its evolution is like a tone-rich musical theme in which no bounds can be imposed on the combinations, reiteration, and amplification of tones.

Nearly all existing concepts of the personality emphasize the purpose as the system-shaping and mentality-dictating feature. In global terms the purpose is the ratio of the society's rewards for the personality's contribution to it. The components of the purpose are the motivational sphere and objectives.

When one's activity ceases, the motivation may continue in another. Consequently, the motivation-activity link is mobile. The motivational sphere of the personality is dynamic and the dominating motivations add up to the core of the personality. Every period in man's life culminates in a restructuring of the motivational sphere, in differentiation and integration of the motivations, and in shifting the conscious-to-unconscious ratio.

The struggle of the motivations cannot be understood unless analyzed in the social context.

At least equally interesting is the sphere of abilities, a set of an individual's psychological features which make him capable of acquiring fairly easily certain skills or achieving certain objectives. Even so, at any given time society "invites" a specific kind of abilities. It is in this light that imitation, rivalry, or cooperation should be evaluated as factors enhancing or thwarting man's abilities. Man realizes his abilities in a specific socio-historical context. Ideally, everyone would exert all his abilities for the benefit of society and be rewarded accordingly.

In studying the patterns of and conditions for the development of abilities, the psychologist cannot do without cooperation with natural sciences and also with pedagogy, sociology, and medicine. The abilities were once believed to be inborn and invariable features of a person. Neither training nor education in the broadest sense nor the social conditions could allegedly have any impact on the development of abilities.

This theory was refuted. Then the opposite view prevailed, that any ability can be nurtured by proper education. At a still later stage the abilities were believed to generate and develop in social activity from some innate anatomical and physiological capacities which can express themselves in different ways depending on the social environment.

The relation between the inherent features and abilities was said to be multivalued in that similar innate capacities may evolve into different abilities, and dissimilar capacities, into similar abilities.

But what then are these capacities? What is their structure and the dynamics of maturing? To answer these questions, psychology needs the aid of biological sciences, above all, physiology and genetics. Thus social sciences could objectively analyze the human environment while natural sciences could provide an insight into the physical prerequisites for the development of abilities.

This kind of aid is essential even in narrower research such as the studies of perception or eye movement. We in the Institute of Psychology studied eye movements in newborn infants and found that the basic types of movement at this earliest stage of ontogeny are the same as in adults. Now we expect the geneticists and physiologists to help us determine whether these movements are genetically built-in.

Development of man is a major research field where the efforts are concentrated on the human organism and the personality, the former being the subject of biological sciences and the latter, of social sciences. Both characterize an individual as a representative of the *Homo sapiens* species and a member of society. The personality is described in terms of a set of social qualities. Detailed descriptions of human anatomy or of the physiological processes inside the human organism cannot provide an understanding of a per-

sonality's qualities much in the same way that the value of a commodity cannot be understood, in the words of Karl Marx, if social laws are neglected.

Education processes would improve if we knew more about the development of a human individual. Unfortunately, no integral picture is available thus far. Dualist ideas of man are quite widespread in this field of research.

The development of an individual is, however, a process incorporating the development of a personality, development of an organism, and psychological development which are but scientific abstractions designed to describe the same multifaceted process. In this field the importance of psychology as an integrating science for all kinds of research of man cannot be overestimated. We in the Institute of Psychology study man himself, his psychic qualities and features, his perception of self, his interaction with other individuals and the entire society, and his various links with the natural environment and the man-made environment which is continuously and on an increasing scale enriched with new elements.

The Institute of Psychology conducts comprehensive theoretical, experimental, and applied research. If these research efforts are visualized as a building, then its upper stories are occupied by the philosophical and methodological research and the studies of man's development processes in the framework of social relationships. The psychologists on that floor combine their efforts with those of philosophers and sociologists, historians and lawyers, ethnographers and economists (economic psychology is a rapidly expanding interdisciplinary field of research now).

A lower storey is taken up by operational research of human activities and of human communication processes. There the psychologists interact with scientists from many applied fields, notably technical and medical, and are direct-

ly involved in the training of pilots, flight controllers, physicians, and engineers.

The storey further down is concerned with psychic processes such as perception, memory, and thinking, in particular, operational and creative thinking. These stories are not isolated. We found that groups solve some intellectual tasks much better than individuals. Thus in joint visual search the effectiveness of problem solving improves with the teamwork of the partners and the quality of communication (not necessarily verbal) between them. Joint reproduction of a topographical map or a verse is more complete and accurate than the sum of individual perceptions. Man makes a better use of his own memory if he assumes that other people have also memorized part of the picture or text.

Equally enlightening is research into stress phenomena where socio-psychological, personal, and neurophysical determinants are intertwined.

The ground floor is taken up by research into the neurophysical fundamentals of psychic phenomena. The systems approach as a general methodological principle is employed in studying the activities of the brain.

Comprehensive studies of man at the Institute of Psychology of the USSR Academy of Sciences have culminated in findings that are useful to other fields of research. Numerous results are helpful to society and individuals even now. The potential of society of man is infinite as is that of *Homo sapiens*.

Brain and Intelligence

Natural Intelligence versus Artificial Intelligence: The Philosophical View

P. K. ANOKHIN

Research in the brain, in its fundamental mechanisms, and in its molecular structure is probably the most challenging scientific field. This research is expected to culminate in reasonable brain control and in using the laws of its functioning to design various machinery which would accelerate the technological revolution.

In response to a question, whether highly sophisticated intelligent machines would be able to enslave man, Norbert Wiener, the pioneer in cybernetics, said somewhat ironically that if this happened at all, man would be to blame.

However important the field is, application of the findings of basic research in brain activities to control engineering encounters formidable difficulties for lack of fairly complete models of artificial intelligence which would be consistent with state-of-art knowledge of brain activity in natural conditions.

Natural versus artificial intelligence is also a field of research where various philosophical questions have to be answered. Indeed, the thesis of materialistic philosophy that matter is primary and mind is secondary establishes a historic relationship between these phenomena since we know that an inorganic world had existed long before life started on this planet and so the intelligence has to reflect the laws of the inorganic world and comply with them. If so, all

the properties of intelligence had to evolve from the preceding organic forms and, consequently, be capable of dealing with objects of the outside world.

To put it differently, natural intelligence (in primitive form, animal intelligence, and in higher form, human intelligence) is operated by objectively cognizable processes and mechanisms.

It is obvious that intelligent devices cannot be designed unless a fairly solid "conceptual bridge" has been constructed for man to put the available knowledge of brain operation to the most efficient use.

Most Important Feature of Intelligence

In designing artificial intelligence the researchers found it necessary to define the intelligence and its features so as to make cooperation between neurophysiologists, psychologists, and engineers enabling them to embody these features in models and hardware.

McCulloch succeeded in developing a neuron network because he had identified some logical patterns in brain activities and used them in designing an image-recognizing and "thinking" machinery. Since then artificial intelligence became a field extensively explored by neurocyberneticians rather than neurophysiologists who preserved the "reflectory" mentality of the classical neurophysiology that gave no clue to understanding the specifics of intellectual activity. As a result, neurophysiological propertes of intelligence remain a chartless field. Consequently, contacts between psychologists, neurophysiologists, and control engineers are scarce.

Researchers in artificial intelligence have, however, scored significant successes in studying precisely those brain properties which were left out by physiologists.

P.A.P. Moran was probably the first control engineer to come to a conclusion that intelligence cannot be understood and an intelligent machine cannot be developed if that machine is incapable of prediction. The predicting ability is what makes all the difference between the human brain and most sophisticated computing hardware.

According to Pavlov, the conditioned reflex is predictive. Our analysis has revealed that the conditioned reflex incorporates a mechanism evaluating the ensuing situation by, or analyzing the result of, the response.

Neurophysiological research, however, ignores this mechanism because the dominating understanding of the nervous system activity, the principle of a reflex arch, leaves no room for the prediction.

Indeed, the nervous excitation caused by stimulation of some receptor is transmitted, according to the reflection theory, through every point of the reflex arch. Prediction, on the other hand, assumes "running ahead" of the excitation; as noted by A. Uttley, the processes and physiological mechanisms which are not supposed to make their presence felt before the final stage of the reflectory action are certainly there from the very beginning.

The computer of the control mechanism can continuously calculate for every pre-tested control motion the probability that it will lead to the goal. Uttley thus emphasized the guiding importance of the goal for all the actions which accelerate the events.

The value of the goal and prediction has been most thoroughly discussed by Fogel, Owens, and Walsh. In defining the "artificial intelligence" they try to find the characteristic feature which would be common for both natural and artificial intelligences. They are perfectly right when they concentrate on the logic of the mechanisms which add up to the intelligence rather than on the subtlety, accuracy, and

speed of performing specific activities. The foremost among these mechanisms are the decision making and prediction, or goal formulation, mechanisms.

This definition of intelligence encompasses the most sophisticated forms of behavioral activity such as goal formulation, decision making, and prediction. Unfortunately, the important and characteristic factors are merely listed rather than presented in a logical relationship or sequence which would firmly tie them up in a systems determinism.

Indeed, in that definition, as in many others, the goal is something given in advance, and a chain of behavioral acts is only to lead to the goal. But how did the goal come into existence? What factors and processes have contributed to its emergence and made it a mechanism which directs the specific strivings of the organism?

Similar questions could be posed about decision making. What are the factors that compel the organism to choose a particular option? In making a decision the process of choosing an option, most suitable for the situation, is continuously at work. But in what way does this proceed? What neurophysiological mechanisms dictate the choice of a single behavioral "degree of freedom" from millions of possibilities?

These questions are usually studied separately rather than as a logical sequence which forms a behavioral act; consequently, correctly identified factors of natural intelligence such as prediction, goal, and decision making remain isolated fragments that do not integrate into intellectual functioning.

The chief weakness of research in basic specific characteristics of the natural and artificial intelligence at this stage can be identified as lack of a model which would incorporate all the stages in the generation of intellectual acts. Such a model should obviously represent also the neurophysiological mechanisms of every step of intellectual processes.

Brain models such as "predicting" hardware were expected to lead to significant breakthroughs. For such models to respond reasonably to future phenomena they should have such properties and mechanisms as an acceptor of response results which would enable formulating the goal of the behavior, predict the result, and continuously monitor and compare the result and the goal. These are exactly the properties that are lacking in every existing model of the brain, or artificial intelligence. A model which would satisfy the researcher cannot obviously be built unless neurophysiological data are used for continuous updating of the model.

In studies of biological systems any behavioral act is assumed to culminate in an action, the useful result not being included into the process as a physiological category in its own right. This is precisely the cause of the tragic misunderstanding between neurophysiologists and psychologists. For the latter the goal and decision making are essential factors in studies of intellectual processes.

The Functional System as a Logical Model of Artificial Intelligence

Neurophysiology tends to isolate individual mechanisms of the brain for experimenting and studying their properties. This analytical tool commonly used in many biological sciences has yielded impressive results but is only useful at the stage of data accumulation and in preparation for broad generalizations.

All functions of the organism, notably the functioning of the nervous system, are logically integral and so the understanding of their biological significance depends on the "ultimate synthesis" which would show the actual contribution of every mechanism to the whole.

When many years ago we studied compensation of disturbed functions we came to a conclusion that all the factors of activity such as memory, emotions, and the goal make an organic unity which alone can restore the function. Because this unity was systemic we termed it the *functional system*. This is a complete machinery responsible for the activity of any living organism and consisting of numerous mechanisms which act together to ensure logical and physiological generation of a behavioral act.

The functional system overcomes the weaknesses of earlier intelligence models. As noted above, most researchers regard the decision-making mechanism as primary and existing in advance of all other processes involved in an intellectual act. This approach cannot satisfy an impartial thinker, for decision making should be preceded by very complicated processing of multifarious data.

We referred to this stage of an intellectual act as *afferent synthesis* because during that synthesis the brain simultaneously processes most various data arriving in the central nervous system from the outer and inner worlds. Numerous excitations are synthesized at this pre-decision stage. As the entire behavioral act, this stage is dictated by the emotion or motivation prevalent at that time and is represented as an urge or need, as the psychologist would say. This dominating excitation, as shown in experiments with simple needs such as hunger, thirst, or sexual desire, is capable of retrieving from numerous synaptic formations of the brain whatever was related in the past with the satisfaction of, or release from, a particular need, prevalent at the time.

As the excitation propagates through the brain neurons, other excitations are triggered by the totality of environmental factors.

Consequently, as confirmed by experimentation, in every neuron of the brain cortex excitations of three different

sources are simultaneously processed, namely, internal excitation resultant from formation of a prevailing motivation; external excitations caused by the environmental situation; and memory excitations triggered by both the motivation and the current situational afferentation. It is only by simultaneously processing these excitations and comparing their combinations with the past experience that the organism is able to make a decision leading to a useful result.

Experimental research suggests that all these excitations and sometimes also a triggering factor such as a conditional signal have to arrive simultaneously at the same neuron or, to be more precise, at each of the millions of neurons.

At the pre-decision, or afferent synthesis, stage the overriding question is answered whenever a behavioral act is formed, namely, what useful result has to be obtained in this particular situation and with this combination of excitations?

Only consistent research of this stage can lead to a stringently deterministic explanation of the decision making process. Indeed, micro-electrode studies of some cortex neurons have revealed that the initial data is processed with the aid of numerous dynamic mechanisms which biologically generate a decision, most appropriate in a given situation, and ensure its most faithful execution. Thus the activating mechanisms of the subcortical area (such as the hypothalamus and the reticular formations) look after the establishment of an association and extraction of information from the memory. The same activating excitations significantly increase various abilities of nervous elements in the brain cortex, in particular, the ability to have various excitations converge on them. Another ability is the amplification of excitation reverberations between the cortex and subcortical areas, which results in the most productive synthesis for the purposes of decision making.

Neurophysiological Aspects of Decision Making

An insight into this important synthetic process in intelectual activities is enhanced by viewing an individual neuron and millions of neurons as units which have an infinite number of degrees of freedom in the sense that neurons are capable of generating various configurations of nervous discharges.

The total number of the degrees of freedom in the brain would need a 9,500,000 km of tape to be recorded. This is the "keyboard" where hundreds of millions of "tunes", or behavioral and intellectual acts, are played.

At any given time the brain and organism have a virtually infinite number of degrees of freedom. If all of them were to be put in action at once, the behavior of the organism would be monstrously chaotic. Reasonable behavior of man and animals would be out of the question without constraining this variety. Consequently, decision making is essentially the choice of one degree of freedom that meets the demands of the situation in the most adequate way. It is thus required to determine how the brain makes the choice from thousands of millions of degrees of freedom so as to obtain a useful effect in the situation at hand.

A careful study of the general sheme in which the key mechanisms of the functional system operate reveals that the decision making is aimed at producing the result which would be most consistent with the prevailing motivation. The observations of the latest years prove, however, that at the stage of afferent synthesis not only the general afferent features of the environmental situation but also the attributes of the results that have earlier been obtained in similar motivational and emotional states are retrieved from the memory.

To put it differently, the brain possesses a striking ability not only to recognize particular features of events but also to evaluate the utility of the results obtained earlier in similar situations. The past results can be successively extracted from the memory and compared with the needs of the current situation until the prevailing motivation is quite compatible with one of the past results. This search for the remembered results and comparison with the need of the current moment seems to be one of the most remarkable abilities of the brain.

Generated in the emotional structures of the brain (hypothalamus, the limbic system and the reticular formation), motivational excitation involves those brain structures which store the results of different satisfactions of this motivation in the past.

Thus, the appetite state exists when the lateral hypothalamic nucleus is continuously stimulated by "hungry" blood. Assending into the cerebral cortex, this excitation mobilizes elements of the experience with this particular motivation. The individual searches through the possibilities of quenching this excitation in the situation at hand. To put it plainly, the individual thinks of the place where he could have something to eat; he may say that he will not go to a particular restaurant where "the food is poor".

What is then the neurophysiological significance of this decision? Searching through all possible ways to quench the food motivation, the individual extracts from his memory, in addition to the information on a past visit to that restaurant, the results of that visit, or recalls the food and his sensations in eating it. Under the effect of the prevailing motivation the recollection process includes practically the entire functional system, including the mechanism of evaluating the result.

What is especially striking here is that the intelligence

combines in a harmonious way the most important neurophysiological factors that are needed to make a decision (e.g., hunger or situation) and the entire variety of the past experience in satisfaction of the food motivation. This interaction system seems to have very little in common with the actual brain structure. But every element of our intellectual activity relies on a quite specific neurophysiological mechanism.

The decision making thus seems to result from the preceding afferent synthesis where all past results of actions and all past evaluations of these results are retrieved from the memory and examined in the light of the current prevailing motivation. It is for this decisive stage that the reverberation process is needed so that the entire memory is searched. Decision making is therefore a procedure whose result is chosen as the most adequate for the current situation, following the evaluation of "stored" results.

Neurophysiologically this process obviously amounts to continuous scanning of various results, the prevaling motivation being a benchmark. In some of our experiments corticohypothalamic reverberation was quite vivid.

The Action Result Acceptor

In this Section we will proceed analyzing a neurophysiological mechanism which provides an explanation of the miracles of human psyche such as the goal, prediction, error, memory, and expectation. All of them are found to have the same neurophysiological core which comes into existence at the time of decision making (or somewhat later). It is the neurophysiological prediction mechanism which we earlier referred to as the action result acceptor. What are the nature and functions of this mechanism?

In searching through all the features of the past results and comparing them with the current prevailing motivation, this mechanism accumulates all the afferent attributes of the final result to which the decision is to lead.

Thus, if a decision has been made to take a glass from the table, the acceptor which is generated at that time knows all the relevant features of the glass such as its appearance, weight, tactile specifics, temperature, etc. The purpose of this mechanism which runs ahead of the action and predicts the properties of the future result is to obtain all the data on the parameters of the action once this action is completed. It is precisely at this time that the result which was predicted in the acceptor is compared with the actual result.

At the time when two excitation complexes are compared the nervous system monitors the action just performed. If the comparison reveals that the predicted parameters in the acceptor of the future result coincide with the actually obtained parameters, the action ends, and its result is "endorsed" and used in the generation of the subsequent behavioral stage. If the results do not coincide, then the difference triggers the designing and choosing of a new, more accurate program of actions leading to the desired result.

Since our behavior is virtually a continuum of major and minor results, the nervous system performs such comparisons continuously. Even such activities of little consequence as opening the door to the staircase, going downstairs, taking a bus, etc. are subjected to evaluations after which the subsequent goals are formulated. Even such activities can be subdivided into smaller ones such as setting foot on the first step, on the next step, etc. The nervous system should receive information of every small result and this information is processed in the appropriate acceptor. In response

to every minor difference between the prediction and the result (e.g., the individual stumbles) the brain instantly chooses a new motion.

This brief description of the mechanism explains its name. The Latin *acceptare* means both "receive" and "approve", and the two meanings are reflected in the functions of the action result acceptor.

What is then the significance of this mechanism in the intellectual functions of man and animals and what is the value of this approach in the development of artificial intelligence? First of all this is a result-forecasting mechanism. The action result acceptor is also a goal machinery because in all our actions the achievement of a result is conducive to a specified goal. The goal as we understand it in our experiments is not something given in advance but is prepared by a complicated operation of the nervous system at the stage of afferent synthesis. The goal can therefore be defined as a psychological concept in the language of neurophysical mechanisms and objectively existing causal links between the processes occurring in the brain.

The analysis of prediction and goal formulation brings to the fore the philosophic aspect of research in intelligence and its treatment in terms of the functional system.

Until very recently we did not try to resolve the following paradox: every thinking person is well aware that he formulates the goal to achieve "something" long before he materializes that "something". But the brain physiology did not have tools to explain the mechanisms whereby the brain specifies a "goal" for man and can predict its realization.

Once neurophysiological patterns shaping the higher functions of the intelligence were discovered, the thinking in this field has radically changed. The field is now being successfully explored and true intelligence modeling becomes an increasingly feasible proposition. The concept of

a functional system encompasses all basic mechanisms of natural intelligence.

In electrophysiological experiments any new component can be introduced into and removed from the action result acceptor (this is referred to as acceptor enrichment), which significantly increases our potential of influencing the human intellectual activity such as learning.

Evolution of Basic Intelligence Characteristics

At this point a question arises, are the above-described basic mechanisms specific only to higher animals or even to man alone? This is a basic question closely related to other questions such as: do animals possess intelligence? and when and in what animals does it emerge in the process of evolution?

Fogel and others tried to develop an evolutionary model of artificial intelligence which was to improve its main properties via the sophistication of primitive mechanisms through a chain of "generations". Note, though, that in modeling the experience is generalized in a somewhat different way than in evolution.

Before answering these questions, one basic finding of many years of research has to be formulated. None of the above properties of brain activities which are regarded as characteristic features of intelligence emerged abruptly, upon crossing some evolutionary frontier before which it did not exist.

All these properties were incipient when life began, and even at that time they were integrated in the dynamic physiological architecture. Furthermore, they were a condition *sine qua non* in the development of living beings.

This may seem strange because intelligence has for ever been described as an outstanding feature of the living matter, inherent in at least the most sophisticated representatives of the animal kingdom.

This problem is resolved when we imagine the way in which intelligence came into being. Let us take up for illustration the prediction of events or results of an activity performed by a specific functional system.

Under what external and internal conditions is prediction possible? Prediction is made possible, first of all, because the sequence of events about which a prediction is made has occurred many times in the past. Our intelligence predicts that an evening will follow the day and this will be followed by a night just because this sequence has been occurring for millions of years.

At this point it will be useful to forget for a moment the specific neurophysiological processes and mechanisms and turn our attention to more general reasoning.

The space-time continuum of motion of matter is, as noted by Planck, an absolute law of the universe which had existed long before life began on the earth. Life, or living beings, had to be compatible with this law if they were to survive. This compatibility, or reflection of the world's time — space structure in the living beings became a prerequisite of prediction.

The application of this reasoning to biological phenomena suggested a principle of predictive reflection of a sequence of actual events by the brain. This reflection is an inherent property of protoplasmic processes even in primitive animals for which, for instance, seasonal changes have invariably occurred for millions of years.

Scores of instances of the striking accuracy with which living organisms adapt to the patterns of the inorganic world can be recalled.

In effect, the discovery of the conditioned reflex by Pavlov was essentially the discovery of the predictive reflection of the external world in a highly specialized substrate which is the nervous system. Indeed, salive secretes in a dog in response to a bell not because the bell will have to be digested but because food to be digested will arrive. Consequently, repetition of a sequence of certain external events creates a chain of easier responses which can be triggered by a certain nervous signal; then the chemical reaction of the protoplasm propagates through the nervous system ahead of the external events, as if in a miner's fuse.

"Prediction" as a phenomenon of an isolated intellectual act is thus historically deeply rooted. At the higher evolutionary stage the nervous system became the organ of this anticipating process and made such processes hundreds of times faster and more accurate; it is for this reason that we can make an almost fantastic voyage into the future in response to a signal from the external world.

The evolution which started with primitive protoplasmic "prediction" has improved this process in material phenomena inside the brain to such a degree that the brain now combines in its functioning the past, the present, and the future.

This is not wishful imagination of a neurophysiologist. Implanted microelectrodes reveal that some neurons subjected to stimulation make use of the experience for simultaneous generation of processes which combine the features of the results which will not be received until some time in the future. We refer to these brain cells as "neurons of three time domains".

Afferent synthesis culminates, as noted above, in making a decision which is the outcome of search through possible results that are organically related in the past to a given motivation. In this way the nervous system models the pro-

perties of an anticipated useful result, the goal, which has triggered, and for which has developed, the afferent synthesis.

* * *

The basic properties of natural and artificial intelligences will never be understood unless neurophysiology rearms itself with new ideology and develops new tools and methodologies.

The first and foremost need is to use the systems approach which would make it possible to study the highest forms of brain activity such as decision making, goal pursuance, and prediction.

The concept of a functional system will bring science closer to resolving some mysteries of intelligence.

References

1. Fogel L., Owens A., Walsh M. Artificial Intelligence through Simulated Evolution. J. Wiley & Sons, Inc., New York, 1966.

On Reliability of the Brain

A. B. KOGAN

All living beings can to a surprising degree adapt to most various, even extraordinary or extreme situations. A striking example of this purposeful self-control is the high reliability of the brain, a major subject of research in cybernetics which tries to employ certain features of the brain functioning in industrial hardware.

The millenia-long evolution made the human brain a very effective and highly reliable data processing and control

system which goes on functioning even when injuries disable millions of nervous cells. The case of Phineas Gage, a road master whose skull was pierced by an iron rod and who maintained his mental abilities, is widely known. Louis Pasteur continued fruitful research and made significant discoveries even when almost half of his brain ceased functioning after a stroke.

Experiments with animals confirm the surprising structural reliability of the brain. Rats in which about 40 per cent of cortex has been removed do not show any memory disturbances in acquired behavioral skills. Pavlov referred to the unique ability of the brain to withstand injuries as mechanical immunity. Recalling that, according to some neurophysiologists, 100,000 nervous cells die in one's brain every day, the ability of the brain to function is astonishing.

This ability of the brain can hardly be explained in the framework of the reliability theory developed for machinery. The characteristics such as longevity, maintainability, and failure-free operation are inapplicable to biological systems. The longevity criterion makes no sense because thousands of elements die daily but the system carries on. The maintainability criterion does not work, not simply because the successes in transplantation have not extended to brain structure, but also because even if brain could recuperate physically as damaged skin does, this would occur gradually through tissue restoration, but not as fast as was observed after brain injuries. Finally, the widely spread concept of the mean time between failures would imply a failure of the brain as a result of exhaustion or disease; these are, however, the exogenous operating conditions rather than properties of the brain. True, if the mean time between failures were to imply the statistics of correct and erroneous decisions, a certain insight into the reliability of the brain activity

would be provided. This characteristic would not, however, work in all situations.

The conventional approaches are not enlightening as far as the brain is concerned because the nervous system does not obey the well-known rule that the reliability decreases as the number of active elements increases. The opposite is true, the simple spinal reflexes where as few as hundreds of thousands of nervous cells are involved are less stable to injuries than the cerebral cortex which consists of billions of neurons and so would be expected to fail continually.

The high reliability of the brain can hardly be explained as replacement of failed elements or areas by their stand-bys, by analogy with "cold" and "hot" redundancies in hardware. With the tremendous variety of the functions performed by the nervous mechanisms of the brain, multiple redundancy would have resulted in a quite fantastic size of the system.

This reasoning suggests that the brain is made reliable by mechanisms which are dissimilar to those in technical systems. This is probably the explanation of the failure of numerous attempts aimed at using technological tools to develop super-sophisticated data processing and control systems which would reproduce the logical activity as reliably as the brain ensures reasonable behavior in a highly variable environment during the entire lifetime of the organism. Indeed, as far back as in 1943 W. McCulloch and W. Pitts theorized that superposition of logical operations such as disjunction, conjunction, negation, etc. by the rules of the Boolean algebra in "formal neurons" could result in a system which would imitate any intellectual activity, provided that this activity is unambiguously described in some (natural or formal) language. In implementation, however, technical problems grow as a snowball with system's complexity and build up, in the words of A.I. Berg, full member

of the USSR Academy of Sciences a "reliability barrier" to further sophistication.

What is then the true explanation of the reliability of the brain, a system which consists of billions of parts and faultlessly operates through the human lifetime? The most natural explanation seems to be that nature has found a way to bypass the law of inverse dependence of the reliability on the number of active elements, especially because this law implies that every element performs its own specific function. Living beings, however, are highly adaptable and continuously change through probabilistic rather than deterministic functioning. These facts have led D. Smith and S. Davidson to a paradoxical conclusion that living systems increase their reliability by reducing the specificity of behavior of their elements. An increasing number of researchers believe that the mechanisms of nervous activity are stochastic, their organization statistical, and the neurodynamic reactions probabilistic. What is more, a consistent deterministic approach would call for individual descriptions of billions of neurons in every act of the nervous activity, which is out of the question.

The physiological processes involved in the brain activities, especially central inhibition, self-regulating and self-controlling [1], have a great role to play in ensuring the high brain reliability.

The protective inhibition prevents the overloading of the cortex cells of the brain and maintains their optimal state; sleeping inhibition makes periodic rest possible: coordination inhibition switches the impulse flows to new paths when functioning of the old ones deteriorates.

Another way to improve the functioning reliability of the brain is to use its latent potential such as the redundancy of the working elements which manifests itself, in particular, in multiple links between the neurons and between the

centers so that weariness is avoided by alternating these links. Another kind of latent potential is the duplication of the signal paths (thus, in arbitrary movements the commands to the skeletal muscles are transmitted through both direct and intersecting downward-bound fiber bundles from the cortex through subcortical layers and the spine). The paths of signals from sensory organs to higher parts of the brain are also duplicated. While the functions in the nervous system are highly centralized, the nervous centers are relatively autonomous and preserve the ability to perform their functions even when the links with the higher nervous structures (with which these centers make up a multilevel system implementing complex activities) are severed. Especially important is the ability of the higher brain layers to restructure the existing and form new conditional links in order to offset structural and functional disturbances.

Some research findings suggest that the mechanism of closure of conditional links is such that the brain organization ensures reliable functioning even when the brain is injured. Thus, the maintenance of the conditioned visual-motor reflex in a cat whose brain has been dissected many times between the visual and the motor zones is explained if the conditional link is closed by a process involving the entire cortex rather than through a single excitation "bridge". Figure 18 shows a possible circuit in which numerous conditional links are generated in every micro-area of the cortex between cells which transmit the signal of conditioned stimulus into its projection zone and the output cells of this zone which transmit signals into the subcortical structures of that unconditioned reflex which was responsible for the formation of the conditioned reflex [2].

There is much evidence that in the evolution of living multi-element systems nature overcame the "reliability bar-

rier" by using redundancy in the mechanisms of statistical functioning and a variable structure so as to make sure that failure of some elements is not fatal. This mechanism of reliability in nervous activity has been experimentally confirmed and described in the framework of probabilistic

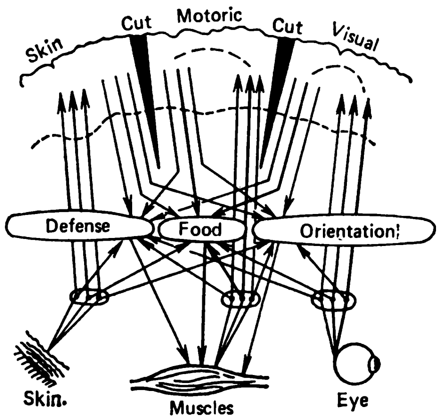


Fig. 18. Multiple closure of temporary links in the cerebral cortex ensuring reliable conditioned reflex action even when direct cortical links are severed

The dashed lines denote closure, and solid lines show signal transmission paths in conditioned reflexes in response to visual and muscular stimulation

and statistical organization of the brain [3]. The properties of this organization manifest themselves on every level of the hierarchy of nervous activities.

Even on the subcellular level the statistics of the set of molecular reactions in biochemical cycles and the dynamics of microstructures reliably ensure a high degree of optimization of energy transformations which are behind the functioning of the nervous system. For this reason the neurons can hardly be described as "unreliable elements" of which a reliable system is built [4]. A major element in making the neuron reliable by maintaining its optimal operation is self-regulation of metabolism through which the nervous

cell has sufficient energy supply for its functioning [5]. Another very important mechanism is the exhaustion-preventing alternation of activity and rest, in particular, the wakefulness—sleep cycle, the various phases of which are behind the rhythms of the metabolic neuron—glya interaction as evidence by metabolic activities [6].

We have considered the probabilistic statistical organization of the working mosaic of elementary neuron networks in the cortex responding to sensory stimuli. In contrast to machinery where every part performs the invariable function and all links with other parts are unchangeable, neurons in a nervous network act in elementary ensembles which perform their functions in a statistical way. For this reason the organism functioning is but little dependent on the state of individual cells. What is more, the increasing number of elements arranged in this way improves the statistical credibility of the functions, though at the price of high degree of structural redundancy (as is obvious in the case of evolution from the spinal cord to higher layers of the brain).

Statisticity as a condition for reliable functioning of neuron ensembles is supplemented with the probabilistic nature of neuron cell involvement into different ensembles. Neurons, whose reactions are most variable, make up a mobile reserve constantly prepared for compensatory restructuring should some neurons fail. Thus, lengthy simultaneous observations of several nervous cells reacting to many repeating stimuli detect a kind of "shift operation" [7]. Figure 19 shows the results of one such experiment. Following a sequence of ten stimulation signals (light flashes at intervals of 10 s) neighboring neurons *1* and *2* alternatively increase and decrease their responses, and when neuron *2* ceases operation, its partner *1* steps it up.

In the activity of the brain as a system, an elementary neuron ensemble in the mosaic which encodes some features

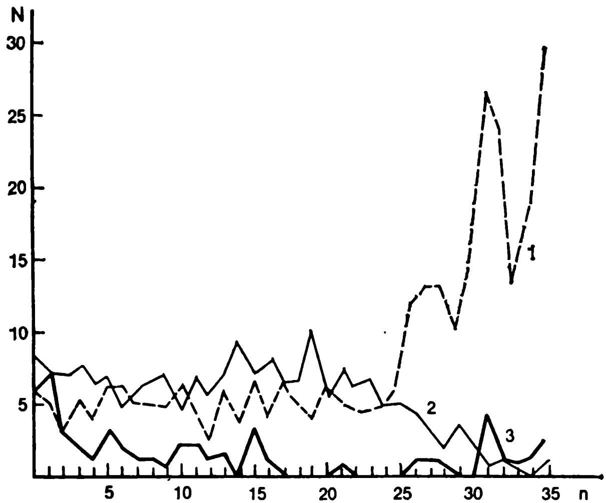


Fig. 19. The dynamics of pulse responses of three simultaneously monitored neurons in the visual cortex of a rat to repeated light stimuli

n is the sequential number of light flashes following at intervals of 10 s; *N* is the number of impulses in the neuron response to a light flash; *1* and *2* are neighboring neurons, and *3* is a neuron 300 μm away from them

of the stimulus acts as a functional unit whose activity and the very structure are largely dictated by the goal functions of the system. The inter-neuron links are continuously restructured in order to change the kind of functional transformations of the input signals and of the actuating outputs. In the model of an adaptive ensemble of Fig. 20, neuron-like elements subjected to specific stimuli continuously vary their activation thresholds and link weights. As a result the input signals undergo various functional transformations.

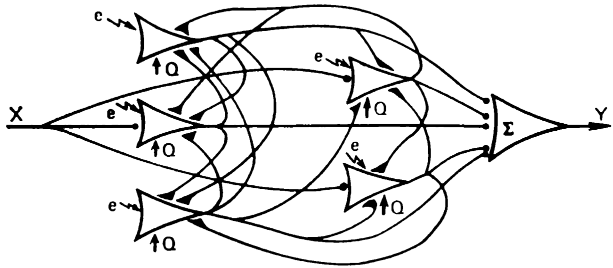


Fig. 20. A model of dynamic neuron ensemble restructuring which makes the functions fit the system tasks

X and *Y* denote input and output signals; *e* are randomizing factors; *Q* are criteria specified by the system goal functions, and Σ is an adder

When some signals in the set of input signals are capable of producing output signals that meet the criteria of the system goal functions, the ensemble "clicks" as an adequately functioning part of the system. The action of the system, however, changes the situation again and so the input signals change, the former functional transformations prove inadequate, and the search is repeated until the optimal structure of the functional units is found in the system.

This self-organization mechanism in which the functional units of a neurodynamic system pursue the system goals makes the adaptation to a changing situation very reliable. The probabilistic processes leading to formation of conditional links [8] make it possible to use different paths in order to reach the goal of activities performed by a behavior system. Thus, a complex motor action repeatedly performed by an athlete with striking precision is found to result every time from somewhat different combinations of muscular contractions but lead to the optimal result.

On the level of the brain acting as an integral system, reliability of performing higher intellectual functions large-

ly depends on the resilience and interchangeability of the system mechanisms. This is precisely why reasonable behavior continues if some sensory systems fail, for other systems act as backups. The blind and deaf have been reported to develop sophisticated psyche and some of them are known as writers. In the education of deaf and blind children the brain is made to perform reliably in intellectual tasks through compensation of some sensory functions by others [9].

Indeed, even though the visual and auditory reception is disabled and so the links with the environment are scarce,

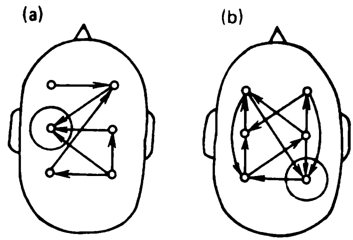


Fig. 21. Distribution of activity in higher sensory system of the brain in a deaf and blind (*a*) and in a normal subject (*b*)

the skin and muscular analyzer is trained to act for speech communication and helps to educate a full-fledged personality. An insight into the restructuring of nervous mechanisms in the higher areas of the brain is obtained by studying its electrical activity which reflects to some extent the performance of the cortical parts of the sensory systems. Figure 21 shows the results of observing the electrophysical indicators of the nervous processes in basic analyzing structures of the cortex in Nataliya K., a deaf and blind Moscow University student and, for comparison, in a normal subject Vitaly D. The causal dependence on the activity of one structure on that of another (shown as arrows in Fig. 21) was studied. Areas where three or more causal actions converge are shown as circles. In Vitaly D. the activities of the occipital

lobe where the vision centres are located dominates while in Nataliya K. the leading role has been taken over by the parietal parts because she perceives the world through tactile and muscular sensory systems which effectively and reliably compensate for the lack of the apparently irreplaceable vision and hearing.

In the complex hierarchy of the brain threre are specific reliability mechanisms on every level. On the other hand, on all the levels the reliability is ensured by redundancy so that the functions are implemented statistically; the elements are multifunctional and can take over from one another. The structural redundancy is supplemented with various functional redundancies, in particular, redundancy of the messages. Even partial reproduction of these abilities in hardware would result in highly reliable and adaptable data processing and control systems of variable structure.

References

1. Асратян Э. А., Симонов П. В. Надежность мозга. М.: Изд-во АН СССР, 1963.
2. Коган А. Б. О структуре замыкательного аппарата условных рефлексов.— Журн. *Высш. нерв. деят.*, 1961, т. II, вып. 4.
3. Коган А. Б. Вероятностно-статический принцип нейронной организации функциональных систем мозга.— Докл. АН СССР, 1964, т. 154, № 5.
4. Neumann J. von, Probabilistic Logic. California Inst. of Technology, 1952.
5. Ефимов В. Н., Рыбак И. А. Моделирование нейронных сигналов с сигнально-энергетическими взаимодействиями.— В кн.: Проблемы искусственного интеллекта. Элиста: Изд-во Калмыкского ун-та, 1979.
6. Фельдман Г. Л., Федоренко Г. М., Гусатинский В. Н. Синтез белка в крупных пирамидных нейронах коры во время парадоксальной фазы сна.— *Цитология*, 1980, т. 22, № 5.

7. Тамбиев А. Э. О межнейронных взаимоотношениях в зрительной коре мозга крысы при нормальной и эпилептической активности: Автореф. дис. .... канд. биол. наук. Ростов н/Д: Ростовский ун-т, 1971.
8. Меницкий Д. Н., Трубачев В. В. Информация и проблемы высшей нервной деятельности: Вероятность и условный рефлекс. Л.: Медицина, 1974.
9. Мещеряков А. И. Слепоглухонемые дети: Развитие психики в процессе формирования поведения. М.: *Педагогика*, 1974.

Novel Aspects

Diurnal Rhythms and Adaptation

V. N. REUSHKIN

Some Remarks on Circadian Rhythms

Certain disorders in the organism are first indicated by changes in the diurnal rhythms. These changes are helpful in the early diagnosis of some diseases and in their treatment.

Let us agree on the biorhythmological terminology. Even the specialized literature uses some of the terms, such as "diurnal rhythm" and "circadian rhythm", in an extremely vague manner. By "diurnal rhythm" we imply variations of any parameter during 24 hours. "Circadian rhythms" are variations with a period of about 24 hours.

There are two explanations of circadian rhythms: endogenic and exogenic.

In the former the functioning of the living organism is assumed to evolve subjected to constant cyclic variations of geoheliophysical parameters caused by the rotation of the Earth around its axis, which is believed to be the main factor in the development and genetic continuation of the mechanism of diurnal rhythms and in determining the diurnal oscillation of the organism's parameters.

The main argument of the exogenic theory is that circadian rhythms originate and persist due to external forces which destabilize the systems of the organism but these tend to regain their equilibrium. The specific external forces responsible for these changes, however, proved hard to detect. Some researchers went as far as to suggest some cosmic forces unknown to modern astrophysics.

Though experimental data was abundant, two mutually exclusive approaches persisted. It seemed for some time that a more elaborate experiment would resolve the problem. Animals were exposed for different periods to either continuous illumination or darkness. After some time, a rhythm with a period of approximately 24 hours was observed in the animals. Why "approximately"? The period was longer or shorter than that, but practically never equal to exactly 24 hours. Hence, its name "circadian" is borrowed from the Latin *circum* which means around, approximately.

Circadian rhythms under such conditions supported the endogenic theory. The experiments, however, were said to have ignored the temperature and barometric pressure, which also vary with a period of 24 hours. So, conditions were created in which these parameters remained constant. A new counter-argument, however, was put forward: circadian variations of the Earth's magnetic field were ignored, etc. Finally, the experiments were conducted under what might seem to be ideal conditions: the animals were housed in deep caves and mines. The same results were obtained. This refuted all arguments against the endogenic interpretation of circadian rhythms.

In discussing circadian rhythms, one has to differentiate between the words "appear" and "are revealed". They imply conceptually different approaches to the origin of circadian rhythms. If a rhythm is said to "appear", this means that it does not exist under normal conditions, but appears when subjected to certain factors. If a rhythm is "revealed", this means that it has always been present, but was simply masked by some spurious oscillations which, combined with circadian rhythms, can be observed only by suppressing background interference. Since the causes of these variations are innumerable, the variety of daily rhythms may be infinite.

There is one more point of interest here. Experimental conditions are not the only factor affecting the period of circadian rhythms. Nocturnal-habit animals were found to have a period of circadian rhythms, at constant illumination, of over 24 hours, while diurnal animals manifest shorter periods. Conversely, in constant darkness the former have a period shorter than 24 hours, while the latter, longer than that. The available explanations are not convincing. We, too, leave this question unanswered for the time being.

Why Can't We Find a Biological Clock?

Since circadian rhythms are endogenic, one can assume that animals have a biological clock — a pacemaker. Theoretically this may be some endocrine organ, or even a small group of CNS cells. The search for the biological clock has been unsuccessful for a long time. But eventually sensational news was announced. The biological clock was allegedly found. The daily rhythm of the motor activity of a cockroach was found to be dictated by a conglomarate of nervous cells located in a subpharyngeal nervous formation (subpharyngeal ganglion). This news revived the hope that the clock in vertebrate animals would, in time, be found too.

There were repeated reports on detecting biological clocks. All of them, however, were subsequently refuted. The misunderstandings were usually caused by the fact that the isolation of some elements of the neuro-endocrine system eliminated the diurnal rhythms. This was sometimes interpreted as an indication of the precise location of the biological clock. Some time after the surgery, however, the diurnal rhythm returned to normal. This led to the suggestion that vertebrate animals may have several clocks. In other words, a living organism has pacemakers which are either totally independent of, or depend very little on, one another. More-

over, under normal conditions, the diurnal rhythm is determined by a specific clock. If the clock is isolated or removed, its function is delegated to other clocks which either have not been involved or their influence has not been previously dominating. This is how the multioscillatory theory of biorhythms originated. Without appealing to the achievements of advanced biochemistry, no other explanation of the phenomenon is acceptable.

Until recently there was a single opinion on the secretory funcion of the endocrine glands. It was believed that the organism strived to maintain the required level of hormones in the blood, notably that of the adrenocortical hormone. External factors cause a gradual rise in the hormone concentration which can persist for a long period of time, especially when the organism is exposed to intensive and continuous stressors. The concentration of the adrenocortical hormone in the blood increases to a certain level and stays there for some time. When it drops dramatically, the animal dies.

The secretion of one hormone was found to be regulated by different mechanisms. Thus the basal hormone level in the blood and a sudden (pulsed) hormone discharge are controlled by different mechanisms.

Some data are now appearing to the effect that different diseases disturb either the pulsing secretion mechanism, or the basal one, but not both simultaneously.

These regulatory mechanisms are involved in the formation of diurnal rhythms to different degrees. The leading role belongs to the impulse system which regulates the secretory activity of the endocrine glands.

Now we come across another point of interest. It seems quite natural that an organism responds to an impulsive exposure by a pulsed reaction. Its intensity can vary jumpwise or gradually.

What response can we expect of the organism under such conditions? The study of the diurnal rhythm which is restructured by various stressors has shown that the response (R) is the most intensive at the beginning and at the end of the effect (Fig. 22). Neither the nature of the exposure nor the way its intensity (X) varies are significant. In the

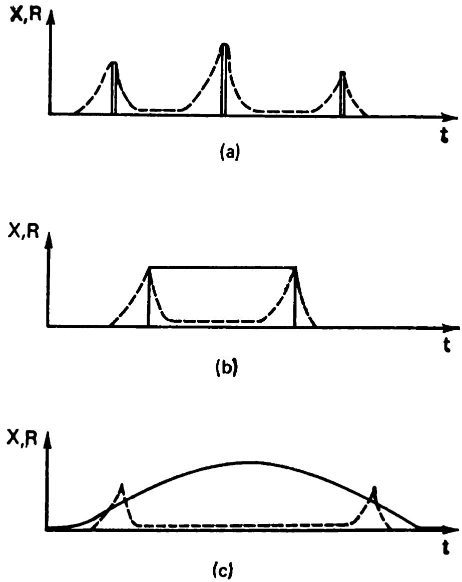


Fig. 22. Pulsed (a), jumpwise (b) and gradual (c) application of external stimuli and organism response to these stimuli

Solid curves plot the intensity X of the external stimulus; dashed curves show the organism response R

jumpwise variation of the latter, the response of the organism coincides with the beginning and the end of the jump. If the intensity of the exposure increases gradually, a pulsed response is observed when a certain threshold is achieved. A similar threshold is observed with a gradual decrease of the intensity. If the exposure lasts for more than 24 hours,

then a repeated pulsed response of the organism is observed 24 hours after the exposure has begun.

These regularities are manifested by various parameters. It should be emphasized that the leading role in the formation of the daily stereotype is played by the impulse mechanism which regulates the secretory activity of the endocrine glands, whereas the impulse response of the organism coincides with the beginning and the end of the exposure. Hence. the same signal, for instance switching the light on and off, is treated as two independent actions.

What is gained by such a response? The results of the following experiment will help us to answer this question.

Anticipation Response

Equal single doses of a poison were administered to three groups of animals according to the following schedule: 1st group — once a day, 2nd — twice a week, and 3rd — once a week.

Common sense tells us that the animals given poison every day would die first, since the total dosage during one week exceeds the dosage administered to animals of the other two groups by a factor of 3.5 and 7, respectively.

The results proved to be quite different. The animals given poison every day lived longer. Only when the poison was administered together with antibiotics were the expected results received: the animals given poison every day died first, and those given poison once a week were the last to die, i.e., the life duration depended on the total dosage of poison.

There results seem to be paradoxical, but let us see what is behind it all.

All stressors cause different changes in the organism; the cumulative effect was termed by H. Selye as "stress respon-

se". In the experiments our attention was drawn to the fact that a new series of changes occurred 24 hours after the initial stress response in the organism of an animal, and this turned out to be common for all animals, including man. The changes were directly dependent on the form and intensity of the factor causing stress response.

Further studies have shown that the stress response is but an initial step in a multi-step process which makes the organism immune to the given factor. To put it differently, the organism prepares itself for a repeated exposure in 24 hours. This is why the second stage of the organism's response to an exposure is called an "anticipation response".

How can the organism improve its resistance against repeated exposure? First, an organism can use its functional reserves, but this would imply a certain overstrain compared to normal conditions. Second, structural transformations also take place. If, for instance, the exposure destroys cells or intercellular structures in some organs and tissues, the organism sees its primary goal not only in their maximal restoration by the time of a repeated exposure, but also in creating some "safety margin".

In repelling attacks of the environment, the organisms of all animals, including man, experience first a stress response, and in 24 hours, a response of anticipation. If an exposure occurs at 24-hour intervals the stress response caused by it on the second day is generated against the background of the anticipation response. Consequently, we experience a mixture of stress and anticipation responses.

The recuperation processes characteristic of the anticipation response gradually reduce the changes which take place during the stress response. During the anticipation response, the proportion of functional and structural components also change gradually: during the first days the response amounts merely to increasing the activity and capa-

city of the organs and tissues involved in the organism's adaptation, while during subsequent stages structural transformations come into play.

Depending on the intensity of the exposure, all responses of an organism can be said to proceed through three different stages. During the first stage, the adaptation process occurs mainly due to an increase in the functional activity of the organs and tissues affected by the given factor. No essential structural modifications take place. This is how the organism responds to a weak exposure. When the intensity is increased, the anticipation response proceeds to its second stage, the stage when the adaptation occurs mainly through structural reconstructions which enhance the potentials of the organism (this is, incidentally, how the organism is trained to overcome physical and chemical stressors). When the intensity of the exposure is increased further the third stage of the response begins. Structural transformations can no longer help the organs and tissues which are now greatly overstrained. This, however, cannot last long. Exhaustion of the compensatory mechanisms leads to the development of diseases which eventually cause death.

An organism's adaptability is essentially affected not only by the intensity of the exposure but also by its periodicity. Thus, monkeys subjected to electric shock at irregular times of the day (heterorhythmic stimulation) developed neuroses rather quickly. This did not happen if the electric stimulation was performed at the same time every day. Much evidence of this kind can be cited. Whatever a heterorhythmic stimulus, the changes it causes in the organism are invariably more profound. According to clinical and experimental data, even weak stimuli of this kind or even frequent disturbances of the daily stereotype exhaust the nervous system.

Without dwelling upon the reasons (many of which rema-

unclear), note only that the anticipation response appears 24 hours after the initial exposure, while the period needed to prepare for the next shock is as short as 1.5-3 hours (depending on the type and intensity of the stressor). This is why frequent violations of the daily schedule, or events which occur at arbitrary intervals, lead to diseases very much like those caused by high-intensity stressors. The restructuring which occurs during the anticipation response does not create the required adaptation, in some cases because of the high intensity of the stressor, in others because of the constant mismatch between the time of the low-intensity stressor and the build-up of the anticipation response.

The time limitations of the anticipation response also explain the results of studies on the impact that physical strain has on the muscule-skeletal system. The best results are achieved by regular daily training of a certain intensity and duration. An increase of either the intensity or duration of the training lowers the efficiency dramatically. This can be easily explained if we know how the anticipation response is formed. The intensity of training should be such that no changes exceeding the second stage of the anticipation response occur. This being the case, the structural modifications fully support the normal activity of the organism. A higher intensity of training causes changes which induce a response amounting to the third stage of the anticipation response. Many systems are overstrained. The training duration is optimal if it coincides with the time of formation of the anticipation response. If the training session is extended, the period of physical strain goes beyond that of the anticipation response. In this case, the organism has to fully utilize its functional reserves.

Irregularity of the training also impairs the organism's efficiency, and the reason for that is quite obvious: the anticipation response fades quickly. The new structural elements

are destroyed and the functional activity suppressed. Athletes who believe that the longer and harder the training, the better, are obviously misled. This might be the reason for the "highly skilled athlete syndrome".

Thus, the anticipation response concentrates mainly on purposeful transformations which are connected with increasing amounts of newly synthesized proteins. This finding has been confirmed experimentally.

Administration of substances which prohibit protein synthesis leaves the organism unprotected from any strong physical or chemical stressors. Antibiotics are also among the substances which inhibit protein synthesis. In light of this, the above experiment does not seem paradoxical any longer: animals which received the poison every day lived longer, although they received amounts exceeding those given to animals once or twice a week, because the regularly induced anticipation response adapted the organism by training it. However, when antibiotics were administered, the anticipation response was inhibited and the life expectation depended only on the total poison dosage, and thus the animals of this group died first.

An even more striking picture was revealed in a study of the damaging effect of ionizing radiation. With an interval between irradiations equal to 24 hours, the damage caused by radiation reduces dramatically. If it is less or more than 24 hours, the inflicted damage is significantly greater. Similar results were obtained with different species by many researchers. The absence of a plausible explanation suggested a conclusion that it was nothing but an artifact, i.e., distortions caused by some procedural or other errors made during the experiment. However, the experimental data turned out to be even more surprising. A radiation dose of 7 gRh was administered to animals, some of whom had been given a dose of 2 gRh 24 hours earlier. Unexpectedly, again most of

the animals twice subjected to radiation survived (about 90 per cent), whereas most of the animals in the other group died (only about 30 per cent survived). With an increase in the first dose of radiation, more animals among those irradiated twice died, and the mortality rate in this group exceeded that of the group subjected to radiation one time.

This fact suggests that an initial irradiation by a 2 gRh dose stimulates the formation of the second stage in the anticipation response, hence a repeated irradiation of the organism during the activation of the functional reserves and specific structural transformations causes a reduced effect.

These phenomena may help oncologists who constantly have to choose between the need to increase the therapeutic dose of radiation and the danger posed by radiation sickness.

It should be specially emphasized that the anticipation response is specific i.e., it is formed in response to a specific stressor and enhances the organism resistance only to that particular type of stimulation. Moreover, an exposure of the experimental animals to some other stressors 24 hours before irradiation greatly impaired their resistance to the ionizing radiation. Why? This question remains to be answered.

Specificity of Reactions Caused by Stress Factors

Academician P. K. Anokhin in his theory of functional systems treated a living organism as a multi-purpose system which pursues its different goals by combining its subsystems in different ways. Such a system acquires specific properties which are different from the principles and properties of its subsystems. In other words, the same elements are

used every time to obtain a new system for performing a specific task. It is the nature of the tack that determines what elements interact and in what manner. "Elements" here imply all kinds of structures, from intercellular formations to organs and tissues. All these elements belonging to different levels are coordinated mainly by the neuro-endocrine system.

All organs and tissues and their intercellular formations participate in various systems which form in response to various stressors. The demands placed on each of the elements and on the mode of their interaction are constantly changing. This may serve as an explanation of the reduced resistance of animals to radiation if the anticipation response was generated as a reaction against a qualitatively different stressor.

However, there are some exceptions to this general rule. An organism can adjust to a certain stressor while simultaneously enhancing its resistance to another, quite different one. This is what we call cross adaptation.

It has been discovered, for instance, that physical exercises enhance the organism's resistance to both high and low ambient temperatures.

An organism exposed to physical loads and low temperatures has to generate more energy, which in the case of physical activity is spent on muscular efforts and in the case of low temperatures, on heat generation. In both situations, mitochondria (functioning like power stations in the organism) form the core element which has to meet higher requirements.

Cross adaptation to physical exercises and high temperature is explained differently. A rise in the body temperature resulting from physical exercises forces the organism to speed up its heat exchange. An elevated ambient temperature, however, causes the same reaction. Hence, an improvement of the heat-exchange mechanisms involved in physical exer-

cises enhances at the same time the resistance to high temperatures.

It is not surprising, therefore, that organisms adapted to high ambient temperatures do not show increased resistance to low temperatures, and vice versa, because deviations of the ambient temperature from the norm activate protective mechanisms depending on the direction (sign) of the deviation.

To put it differently, in either case the organism responds "specifically". The very term "specific" implies that there are nonspecific reactions as well, i.e., the organism reacts in exactly the same way to various types of influences. Hans Selye used this assumption as a vital component of his adaptation syndrome theory which can be presented briefly as follows: all irritants (stress factors, or stressors) activate the pituitary body which secretes adrenocorticotropic hormone which in turn stimulates the secretion by the adrenal gland of the corticosteroid hormones. The corticosteroids in turn affect the organs and tissues thereby increasing the organism's resistance to various stressors. Such responses are now called "stress reactions".

Several decades after the adaptation theory was proposed and its proponents outnumbered its opponents, it seemed that the theory itself was complete, and only the finishing touches must be added. This, however, could not be done for a rather long time because a new question arose: how nonspecific were stress reactions? We faced a dramatic situation. On the one hand, much evidence has been reported recently to the effect that each stressor causes quite specific changes in organs and tissues thereby confirming the specificity of stress reactions.

The search for nontrivial solutions began. Information theory, mostly its technique of encoding and decoding, proved to be of much help here.

The evolutionary process, from the synthesis of the first organic molecules to highly organized systems such as representatives of the animal world today, was made possible due to the constant accumulation of negentropy, i.e., through the constant self-perfection of structures and functions as a result of processing energy and information coming from the environment. It was also in the course of evolution that higher organisms acquired a system of sensitive analyzers which helped them to function optimally in the constantly changing environment. The organism seems to be wasteful with regard to information which should promote the rapid and reliable restructuring of functions to meet the changing requirements. Indeed, abundant information on external disturbances as received by highly specialized receptors is used to produce a nonspecific response of the pituitary-adrenal system.

In the framework of the information theory, any relationship can be presented as a channel transmitting a coded message from the source of information to the user (target). The encoding and decoding units have to ensure that the content of the transmitted and received message is identical. Note that even when an optimal channel is used, only part of the data fed into it is transmitted, and no manipulations with the data can increase this amount.

We can assume, therefore, that information on various environmental changes received by highly specialized receptors is encoded to be transmitted further to the user organs. This data, however, is depreciated during the process of transmission as a result of nonspecific reactions of the pituitary-adrenal system. It is not quite clear in what way the information is restored by the user organs making stress reactions specific. There are two alternatives: either the lost information is somehow restored by the target organ or a specific signal depending on the stressor is encoded by ele-

ments of the neuro-endocrine system. This signal is then received by the respective organs and systems of the organism.

Since it is impossible to restore the information without violating the rules of its transmission, let us discuss the way this specific signal is coded.

As established recently, all endocrine organs are more or less involved in stress reactions. Qualitatively different stressors make their impact in different ways, thereby determining the quantity and priority of the hormones discharged into the blood. The knowledge accumulated so far leads us to the conclusion that the specificity of responses can be attributed to the variation of the hormone levels, their quantitative combinations, and the sequence in which the membranes are connected to the receptors.

There are extensive data showing that one can achieve various effects in the target organs by merely varying the harmonic concentration. Furthermore, the effect of most hormones is modified by other hormones. For instance, intercellular hydrocortizon reduces the synthesis of proteins and accelerates their decay. In the presence of insulin, however, the same hormone increases the synthesis of proteins reducing at the same time their decay.

The Daily Set of Stressors

During a 24-hour period an organism is subjected to different stressors and responds by specific reactions. Such stressors include physical exercises, eating, variations in lighting conditions, ambient temperature, barometric pressure, etc. They follow in a certain sequence in the form of specific impulses. A specific anticipation response to each of them develops in the organism.

Obviously a specific sequence of stressors encountered by the organism during a 24-hour period causes a similar se-

quence of anticipation responses. Since the anticipation responses are generated in advance, their succession and the time intervals between them are programmed accordingly. It seems reasonable to speak not of isolated stressors but of their total effect. Thus, a program for the organism's life for the coming 24 hours is formed on the basis of the entire ensemble of daily stressors.

The adaptation to a disturbance of the daily stereotype caused by a change in the daily regime (as is the case, for example, when a plane takes us across several time zones) depends on the time shift. If the difference between departure and arrival time does not exceed 2 to 3 hours, the shift is not interpreted by the organism as something new. Practically none of the stressors goes beyond the respective anticipation responses, and the adaptation occurs by their synchronous shift in time. The stereotype stabilizes fairly quickly. Transformations involved produce the least stress in the organism. With a time difference over 3 hours, the components of the daily regime go beyond the respective anticipation responses and the organism reacts to all stressors as new stimuli.

The anticipation response of the organism has been found to be more prompt and complete when caused by an event that is more significant for the organism. A less significant event causes a less complete anticipation response. Three or more responses cannot be generated simultaneously.

This is obvious since it is highly improbable that several modifications occur simultaneously in a cell to ensure reliably its resistance to several different stressors acting at once. Consequently, the organism, in full compliance with Anokhin's theory of functional systems, determines the effects most relevant for it, i.e., those causing the most essential disturbances in the organism, and "starts" generating

the specific anticipation response to compensate for the disturbances.

Significance of a factor for the organism is a subjective notion depending on a number of circumstances. For nocturnal animals, for instance, the most meaningful is the transition from darkness to light, while for diurnal animals it is vice versa, from light to darkness. This is quite natural since the animals which have adapted in the course of evolution to a nocturnal life-style are helpless in the daylight, while those adapted to a diurnal life are lost at night. This is absolutety true of man, too. Any one who happens to be in the dusky forest before sunset feels a certain alarm which is not experienced at daybreak with the same amount of light.

The significance of one and the same factor depends also on its correlation in time with other stressors. Animals, for instance, are rather susceptible to changing light conditions, and especially to a change from light to darkness. Another stressor, though acting a bit differently, is food. If rats are fed at the onset of darkness, i.e., when changing from sleep to active life, they adapt rather readily to these conditions. Feeding in the daytime, however, is something abnormal and rate cannot get accustomed to it. Moreover, if access to the feeding bin is limited to 1-2 hours, the animals die in several weeks.

To recapitulate, the combination of diurnal stressors not invoked by evotulion reduces dramatically the adaptability of an organism. One can hardly expect any good from arbitrary violations of the habitual mode of life.

Circadian Rhythms Revisited

What are the mechanisms underlying circadian rhythms? I began my search for an answer to this question by analyzing the varied concentration of inorganic ions (potassium,

sodium, chloride, manganese, etc.) in the rat's organs. The animals were kept under different conditions and subjected to stressors. There was a stage in the study when I believed that the results obtained in the experiments could have formed the basis for a reference table of the changes occurring in the electrolyte concentration in small laboratory animals. However, the diagrams (there were about one hundred of them) did not reveal any circadian rhythms. The results were so confusing and contradictory that they could not be interpreted at the time.

The situation was resolved by computerized data processing in order to represent a periodic function of any complex form by a sum of several sines (harmonics). This processing decomposed the diurnal curves into several simple harmonic components (Fig. 23). One of them had a period of approxi-

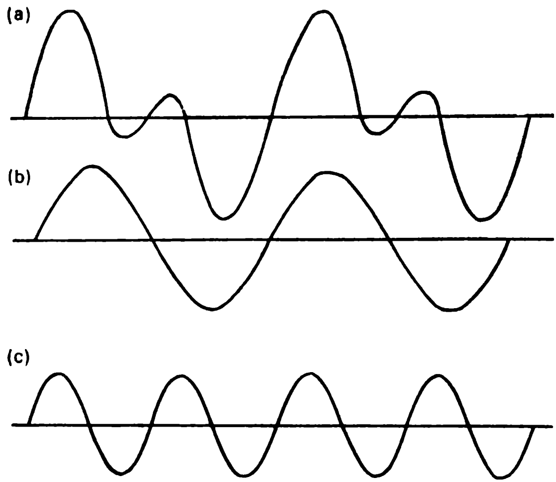


Fig. 23. Decomposition of a complicated periodic function (*a*) into harmonic components (*b*, *c*)

mately 24 hours, i.e., it was a circadian harmonic component, exactly what we mean by "circadian variations".

Several relationships catch the eye. Animals which have been kept under stable conditions for a long time do not show any significant circadian variations, i.e. well-adapted animals do not have circadian rhythms. How about the numerous results confirming the opposite conclusion? There is something wrong here, and we still have to clarify the situation.

There is a circadian rhythm, but it can be detected only in poorly adapted animals, i.e., an increase in the circadian rhythms is observed in animals which are not yet well adapted to certain conditions, and also in those subjected to a stressor a day earlier. It is interesting to note that the more intensive the stressor, the greater the amplitude of circadian rhythms.

Circadian rhythms are not found in healthy and well adapted animals. A reduction in the organism's adaptability caused by some stressor or a disturbed diurnal stereotype leads to the generation of circadian rhythms.

A higher amplitude of circadian rhythms becomes particularly clear during transition processes. When a well-adapted organism is placed in a new environment, the diurnal rhythms start to be gradually restructured till a new diurnal rhythm which meets the new conditions is formed, i.e., a new diurnal stereotype is generated.

During such transition processes, the amplitude of circadian variations gradually grows, reaches its maximum and starts dropping. Along with the increase of the amplitude of circadian variations, the variations of smaller periods gradually fade. The circadian rhythm, so to say, extinguishes them. As the organism becomes more adapted, the reduction in the amplitude of the circadian variations is accomplished by gradually increasing variations typical of a new diurnal stereotype.

The growth rate and the maximal amplitude of circadian rhythms depend on a number of factors, and in particular, on the intensity of external factors. With a higher intensity the amplitude grows more quickly. A similar dependence is observed in the generation of a new diurnal stereotype. The organism under such conditions gets accustomed to the new situation sooner, but at a greater expense to the regulatory mechanisms.

This can be observed when studying the diurnal rhythm for any given parameter. The organism's state is characterized, however, by more than one parameter. We decided to see what would happen to those parameters if animals were exposed to different conditions. It turned out that the adaptation under conditions of different diurnal complexes of stressors occurred via an increase in the amplitude of circadian variations of various parameters. In other words, each stressor induces a specific reaction of the organism, since different systems respond to qualitatively different stressors. This manifests itself in a higher amplitude of circadian variations in diurnal rhythms of quite specific combinations of parameters; this accounts for the specificity of the organism's responses.

Quite unexpectedly one more point of contact was revealed, that between two of the most challenging issues of biology today, diurnal rhythms and the specificity of stress responses.

The same systems have different functional potentials in different organisms. We cannot hope to find two persons who are in absolutely identical states of health. Consequently, the compensatory potentials of a system in each organism are unique and limited. The functional load technique widely used in sports medicine confirms this assumption.

The same stressor causes varying degree of increasing amplitudes of circadian variations in different individuals

(a greater increase is observed in a system with a smaller safety margin). A similar picture is observed within one organism. This permits us to reveal the weak points of each individual and compare the degree of resistance of the same systems in different individuals. Clinically, an interesting perspective opens up.

It is time to summarize what information we have so far.

First, well-adapted healthy organisms manifest practically no circadian rhythms.

Second, an increase in the circadian variation amplitude depends on the state of organism's health and on the intensity of the stressor.

Third, during the adaptation to a new stressor or during the disturbance of the existing diurnal stereotype the circadian variation amplitude gradually increases, reaches its maximum, and then slowly decreases. Each parameter has its own growth rate and maximal amplitude of the circadian variation.

Fourth, in the organism's responses, each type of stressors has a respective combination of amplitudes of the circadian variations.

The above conclusions obtained from the experimental data permitted us to reject the psychological cliché and recognize that circadian rhythm was not a normal rhythm, but on the contrary, an evidence of the abnormal state of the organism. The larger the amplitude the closer the organism comes to a catastrophe. A circadian rhythm characterizes the degree of the organism's inadaptability, which can be caused not only by external (exogenic) stressors, but also by internal (endogenic) factors.

This may naturally invoke counter-arguments which are also supported by experimental data. There were repeated efforts, for instance, to understand the variations during 24 hours in the pattern of resistance to x-ray radiation of small

laboratory animals. They were irradiated at regular intervals during 24 hours. The number of deaths was counted in each group after irradiation. This practically always yielded a good, if not perfect, circadian rhythm. When, however, the experiments used strain animals, i.e., those coming from common ancestors (deviations from the average population characteristics, i.e., heterogeneity, are lower in such

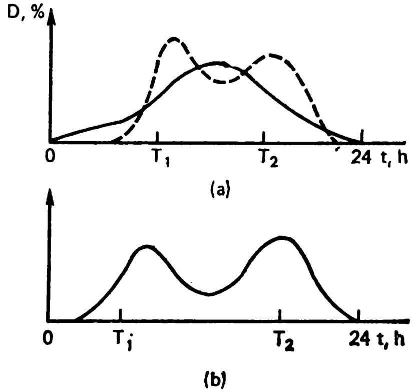


Fig. 24. Distribution of deaths of animals after irradiation at different times of day

Solid curves represent non-strain animals, dashed curves represent strain animals; T_1 and T_2 mark the transition from light to darkness and from darkness to light, respectively

animals in comparison with non-strain ones), the circadian rhythm was replaced by a two-peaked curve, i.e., there were two peaks in the mortality rate. Moreover, it turned out that if in the experiments the non-strain animals were also kept longer in darkness (their period of activity was prolonged) (Fig. 24), two mortality peaks were also obtained.

How can we explain such results? To this end, we have to bear in mind the anticipation response and the fact that external factors are interpreted by the organism as impulses. Switching the light on and off are perceived by the organism as two impulses, and the adaptation to them is facilitated by the anticipation responses generated to both switching

the light on and to switching it off. The organism's resistance to other factors is thereby reduced, including that to x-ray radiation. The highest mortality rate coincides with the transition period from light to darkness and back. Since the heterogeneity of non-strain animals is very high (which causes the variations in the experimental data), well-pronounced circadian rhythms result. If the interval between the impulses (transitions) is made longer, the rhythm disappears. Obviously, in this case we are dealing not with circadian rhythms but with variations obeying the Gaussian law, or the normal distribution of the probability theory. Similar situations are observed in the study of finer diurnal periodic processes such as the variation in the number of different blood cells, the intensity of cell division in various organs, etc.

One more unresolved question: why does the period of circadian rhythms fluctuate around 24 hours? To understand the reason, one has to consider a very interesting endocrine organ, namely, the epiphysis. Although its existence has been known for a long time, the final role of the epiphysis is not yet clear. It is noteworthy that anatomically it is treated as an organ of vision. In lower vertebrates the epiphysis has retained its eye-like state. Hence, it is believed that epiphysis receives information on external lighting via the organs of vision and acts as a component of the biological clock mechanism.

It has been established that the epiphysis secretes substances which can either speed up or slow down the functioning of biological clocks. This can be done by varying the activity of certain components of the neuro-endocrine system. The secretion of some substances increases in the presence of light, while the secretion of others increases in the darkness. Moreover, substances which slow down the biological clocks are secreted in nocturnal animals during the day-

time, while in diurnal animals they are secreted at night. This is why the period of circadian oscillations sometimes slightly exceeds 24 hours in nocturnal animals in constant lighting, and in diurnal animals in constant darkness. The circadian oscillation period can be shortened by reversing the conditions: keeping the nocturnal animals in darkness and the diurnal animals in constantly lighted conditions. Under these conditions, increased secretion of substances which accelerate the biological clock is observed in all animals, and the period of the circadian rhythm is shortened to less than 24 hours.

What Will Cybernetics Say?

Let us return to circadian oscillations. How can we explain the regularities observed? Let us first take a look at the theo-

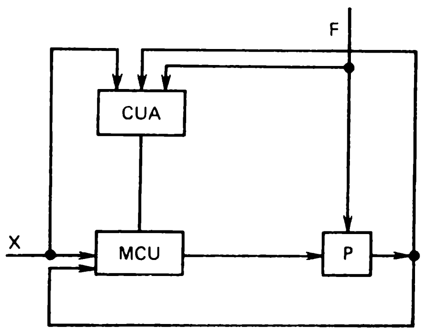


Fig. 25. Schematic diagram of a two-level automatic control system

P—plant; MCU—main control unit; CUA—control unit for adaptation; *X* and *F* denote exogeneous factors

ry of computer-aided control. To be more precise, we look at adaptive control systems (ACS).

In the diagram of an adaptive control system (Fig. 25), one can see that the main control unit (MCU) and the plant

(P) form the main control loop of the system. Negative feedback in biological systems generates self-oscillation processes in the main loop (first regulation level). Information from the main loop elements and about stressors is fed to the control unit for adaptation (CUA), thereby forming a second ACS loop at the adaptive monitoring level. Depending on the deviation from the optimal mode, the MCU is subjected to a stimulus in an effort to eliminate the deviations caused by variations of the external conditions or properties of the main loop.

It is unlikely that the simplified concept of interaction between the two levels of regulation is used in biological systems, since not just one but a multitude of MCUs are subjected to the regulatory effect of the CUA. Still, a regulation system of practically any parameter can be presented with some reservations as a two-level adaptive control system.

Consider, for instance, a system ensuring the required intercellular concentration of electrolytes. In this case the control plant is the specific electrolyte concentration required in the given case. Membranes play the role of MCUs. Their functional state determines the intensity of ion transfer as a function of the concentration gradient. The functional state of the membranes, in turn, depends on the intercellular ion concentration. This feedback closes the first level in the regulation of the electrolyte concentration in the cells of organs and tissues. In general, the neuro-endocrine system plays the role of CUA. Its regulatory effect determines to a large extent the functional state of the cellular membranes. A change in the electrolyte concentration in the blood results in the changes in the functional state of the neuro-endocrine system. This feedback closes the adaptive (second) control loop.

The neuro-endocrine system has to control simultaneously a multitude of first-level systems, because even within a

cell many micro- and macro-elements require this. Since each cell fulfills several functions, in each case there should be an optimal concentration of not one, but several electrolytes. The organism has many organs and tissues and even within a single organ the cells differ according to their functions.

Consequently, the neuro-endocrine system (CUA) should simultaneously monitor many interacting systems of the first (basic) level (MCU).

Since we have the control unit of adaptation and many interacting first-level systems, the distinction should be made between vertical and horizontal links. A vertical link implies a regulatory effect of the second level exerted on the first level, whereas a horizontal link means the mutual effect that the first-level systems have on each other.

Complex multi-level systems can be preserved only if there is an "optimal" degree of interconnection for all elements of the same level. An increased dependence between the first-level elements ensures expedient solutions of the problems they face. However, the cost which has to be paid for this is the tendency of the entire multi-level system to disintegrate. The strengthening of such links is justified only when the system is not subjected to any stressors. When greater demands are placed on the whole system and the first level cannot cope with its tasks, the second level is activated: the strength of the vertical links increases, while that of the horizontal ones decreases. Note that the strength of the vertical links increases steeper when the first-level control systems are less stable. The limited potentials of the first-level systems cause an earlier intervention of the control unit for adaptation.

Within certain limits, each MCU of the first level is given a certain freedom which is limited only by the mutual influence of the elements, i.e., the system is free of the regula-

tory effect of the CUA. This situation is retained until the state of one or several first-level elements does not go beyond the limits set for each of them. This can be the case when an organism has to meet increased demands. In such cases, self-regulatory processes involve the upper level (CUA). The stiffness of the vertical link grows as the intensity of the stressor increases. The mutual influence of the first-level elements reduces simultaneously., i.e., the horizontal link weakens. The regulatory role of the second level is maintained until the functioning of each MCU is brought back within its original boundaries.

How is all this related to diurnal rhythms? In organisms without serious MCU failures, i.e., in healthy well-adapted organisms the pattern of diurnal variations of each parameter is strictly individual.

This behavior stems from specific features of the oscillation processes of each first-level element (MCU). CUAs of poorly adapted individuals are united by the neuro-endocrine system, which is revealed in the larger amplitudes of circadian oscillations and their phase synchronization. Both depend on the intensity of the stressor, or rather, the degree of the non-adaptability of the organism.

What is the physiological meaning of the increase and synchronization of the circadian oscillation amplitude?

We have already mentioned that the anticipation response is the basis of any adaptation process. At that juncture, however, we failed to understand the mechanisms of its formation. It is only now that we can do so.

Any stressor thus causes shifts in an organism, these shifts manifesting themselves in the deviations of some parameters. Each form of stimulation has a specific combination of these parameters. All the deviations going beyond a certain threshold, however, must be suppressed. This is achieved by the organism's preparation for a repeated expo-

sure in advance: if an exposure leads to a suppression of a function, activity of this function will increase in 24 hours. The compensatory increase occurs only for the time during which the anticipation response is formed. This is how the oscillations are formed with a period of approximately 24 hours. If the stressor causes an increase of a parameter, we observe the reversed situation, i.e., the phase of a given circadian rhythm is opposite to the previous one.

The organism's response to any external stimulation is a systemic reaction involving the variation of a multitude of parameters. Hence, one should speak not of a single oscillation process, but of an integrated oscillation system, whose state is determined by a host of many time-dependent parameters. Various factors involve different parts of that oscillatory system. As the intensity of the stressor increases, a large part of the organism is affected and the organism's response involves a larger number of oscillators. An oscillatory system of this type can be described in terms of forces of interaction between oscillators, and an optimal principle of description can be found. This principle is similar to the condition of minimum of potential energy in physics. The interaction between different oscillators can be described by a field of forces. In this case, the system perturbed by the exposure tends to decrease the potential of the field of force.

A specific anticipation response is thus formed by increasing the circadian oscillation amplitude in diurnal rhythms of some parameters, owing to the active intervention of the neuro-endocrine system in the control process. Each stressor induces a unique combination of parameters whose diurnal rhythms show differing increases of the circadian oscillation amplitude, i.e., each combination of these parameters is taken care of by a specific component of the oscillation system.

The growing compensation of the shifts caused by the given stressor weakens the vertical link. The oscillator system consisting of many interacting oscillators evolves so as to reduce the potential of the field of force. Namely, the circadian rhythm amplitudes gradually decrease and new variations with shorter periods appear. By the way, another interesting point in biorhythmology deals with the processes of formation of these new variations and with the role they play in the search for optimal forms of the organism-environment interaction. Finally, the diurnal rhythm of each parameter has a unique pattern.

This interpretation of the adaptation processes is supported by experimental data.

Circadian Rhythms and Health

Let us use our imagination here. We will use the amplitude of circadian rhythms as a strating point.

A person is constantly subjected to different external stimuli which affect virtually all functional systems. Consequently, we may choose several parameters which are easy to measure and are representative of the system's status, and monitor their variation durig 24 hours. Since the circadian variation amplitude increases as the functional potentials of the organism's systems decrease, there is a possibility that we can detect the weakest of the systems long before the clinical symptoms of a disease appear. This is attractive since to date a diagnosis can be made only after clinical symptoms are clearly pronounced. The biorhythmological approach helps with the diagnosis before an actual disease has appeared but the functional reserves of a system in the organism are already impaired. This is primarily true of the cardio-vascular system and, specifically, helps to prevent

myocardial infarctions. To prevent the clinical stage, one can undergo full prophylactic treatment which is much more efficient and less costly than post-infarct treatment.

Assume that a patient wants to know the state of his health. It is precisely the health, not illness that we want to evaluate now, before some latent forms of pathological disturbances appear. Sensors are used to obtain information on the functioning of the organism (in a number of cases contact sensors are not necessary, since it is already possible to monitor some information by remote means); the data is fed to a computer from a distance. Mathematical processing identifies the systems in which the amplitude of circadian oscillations has increased. Having learnt which system is in need of correction, the physician may give qualified recommendations on the optimal life-style to the patient. This is not merely wishful thinking. Almost all individual components of the above picture are known to have been implemented in practice.

Searching Activity, Sleep, and Stability of the Organism

V. S. ROTENBERG

The effect of various types of behavior on and their emotional significance for the stability (resistance) of the organism in face of harmful factors and diseases is a major field of research in today's physiology and medicine. The increasing fraction of psychosomatic diseases (and there is strong evidence that malignant tumors are also psychosomatic) in the total incidence of diseases compels the researchers to look for most general behavioral and psychic factors which

make the organism vulnerable. In recent years stress, notably emotional stress, has been regarded as the most important factor of this kind. In stress the adaptation mechanisms are strained by adverse sensations such as anger, anguish, anxiety, fear, and depression.

Any adverse emotion is known to be traceable to an unsatisfied longing. But while animals are hindered only by the environment in satisfying their "egoistical" desires, man is often hindered by inculcated inhibitions and prohibitions. An emotional stress on most occasions originates from conflict of two equally strong but irreconcilable drives. According to the adherents of the so-called psychosomatic school in medicine, this conflict prevents satisfaction of urgent needs and causes stress, entailing ulcer, hypertension, angina pectoris, and many other ailments which may also result from various factors causing emotional stress such as sudden danger or death of a loved one.

Stress does not, however, necessarily reduce the resistance of the organism or causes ailments. Following the classical definition given by H. Selye, stress is a non-specific response of the organism to any demand (stressor) and this response is designed to overcome the new difficulties and to adapt the organism to changing circumstances. In a broad sense, stress is an ever-present component of life which can under certain circumstances increase the resistance to disease-causing factors.

When and how does the beneficial effect of stress end and the adverse effect begin is one of the most controversial questions in the entire concept. H. Selye has posited a three-phase response to any stressor:

— alarm, a reaction reflecting mobilization of all resources of the organism;

— resistance, when the mobilization helps to overcome the effects of the stress without any noticeable damage to

one's health (in this phase the organism is even more stable than it was before the stress);

— exhaustion, a phase in which the struggle that took too long or was too intense reduces the organism adaptability and thus makes various diseases possible.

H. Selye believed that these phases succeeded in an orderly way.

This explanation seems self-contradictory. Indeed, how can an extension of the state of the increased resistivity abruptly change to exhaustion? Unless some qualitative change occurs, the beneficial effect seems to change perhaps paradoxically to its opposite, especially so because it is still unknown what substance is depleted under stress.

The Selye explanation also contradicts numerous observations. Emotional stress may continue for a long time and be very intense, as in calamities and wars, but the number of serious diseases in people engaged in hard work or war activities was even found to decrease.

It is especially surprising that many survivors of the Nazi concentration camps who prior to incarceration had experienced various psychosomatic diseases showed no signs of them at the time of liberation (even after the extensive stress and inhuman conditions) but the diseases resumed shortly after the liberation.

On the other hand, somatic and psychic diseases may begin once the goal (the desired position or realization of creative work) is achieved if a new important goal is not set. This was the case of Martin Eden of Jack London's novel. In such cases of the "achievement syndrome" there is no stress in the usual sense and no reasons for any negative emotions. But prolonged and intensive struggle, even punctuated with occasional failures, (which amounts to the classical stress model) usually helps to maintain the physical health.

Thus, it is obvious that neither extensive stress as such

nor the sign, negative or positive, of the dominating emotion determine the strength of resistance. In one of his latest books H. Selye emphasized that even the greatest authorities in the field did not know why the "stress of crushed hopes" is much more likely to cause sickness than physical overstrain would [1].

The conventional approaches fail to explain these phenomena because they treat the organism as a passive object of stressors. Man and animal remain, however, active under stress; the intensity of this activity may prove to determine more than anything else the degree of the system stability.

This conjecture was borne out in the experiments with rats and rabbits that were carried out by V. V. Arshavsky, the physiologist, and myself. The zones of the brain that generate positive and negative emotions were electrically stimulated. Since the now classical research of J. Olds [2], known are brain areas whose stimulation makes the animal show, according to the experimenter's design, anxiety, fear, or aggressive behavior combined with the desire to avoid this stimulation; the stimulation of some other points invokes a desire to experience the pleasant sensation again. Thus, if the animal is trained to keep the "pleasure" points in its brain stimulated by pressing a pedal, the animal may press the pedal at a rate of 100 times per minute, forget the food, and ignore its mate. This phenomenon is known as selfstimulation.

The irritation of "displeasure" zones may result in different types of behavior. Some animals react aggressively by biting and scratching the cage, attacking any objects within their reach or breaking from the cage or tearing off the electrodes in order to stop the stimulation. Such active aggressive or escaping behavior is referred to as actively defensive behavior. Some animals show passively defensive behavior.

They make no attempt to discontinue the displeasure, do not leave the farthest corner of the cage but are emotionally upset. Their hair stands on end, the heart beat accelerates and becomes unsteady, the arterial pressure varies, and other signs show the animal's fear. In human terms the rats act as if they expect an imminent disaster.

In other cases the passively defensive behavior is seen as "lifeless" prostration on the floor with the same objective signs of the emotional state. This behavior may be referred to as the surrender pattern. Actively and passively defensive behaviors are also observed in various animals in which natural stresses were invoked; for instance, a cat sees a dog in dangerous proximity for a long time; or the animal is placed in a tight cage; or an animal is subjected to frequent undeserved punishment by painful electric shocks. For man analogous situations would be exposure to extreme conditions or a conflict between incompatible desires.

Both behavioral patterns were found in our experiments to have opposite impacts on the artificially induced pathological states. Numerous human ailments were simulated in animals: epilepsy was experimentally induced by strong and frequent audio irritations or by small amounts of cramp-invoking substances applied to the cortex; anaphylactic shock and other allergic states caused by injection of alien protein into the blood or abdominal cavity; disruption of the heart rate by injection of certain drugs into the blood; a Parkinsonism-like syndrome which followed intramuscular injection of neuroleptics (drugs used in treatment of psychotic diseases and causing muscular constraint and tremor as side effects), etc.

Self-stimulation and actively defensive behavior (aggression and escape) shortly before the pathological states retard their development and make them less pronounced, epileptical convulsions do not start, heart arrhythmia and aller-

gic edema are delayed and made less intensive whereas passively defensive behavior which precedes these states or occurs against their background increases all pathological patterns and may result in the animal's death.

Similar results were obtained in other laboratories and with other models. I. I. Vainshtein and P. V. Simonov showed that actively defensive behavior inhibits, and passive defensive behavior accelerates the experimentally induced myocardial infarction [3]. M. M. Kozlovskaya found that passively defensive behavior may result in stable increase of the arterial pressure [4]. US researchers found that in a hopeless situation which facilitated passively defensive behavior, animals developed ulcers; furthermore, artificially implanted malignant tumors grew when the animal acted passively whereas actively defensive behavior, even under heavy stress, even unsuccessful, resulted in rejection of the tumor [5].

These findings are in good agreement with clinical data that development of somatic diseases in man is often preceded by passivity and depression.

What do then such various behaviors as escaping, aggression, and self-stimulation have in common and in what way are they the opposite of passively defensive behavior? What is the reason for the same positive effect of the organism's stability?

It is not the "sign" of prevalent emotions, for both actively and passively defensive behaviors are associated with negative emotions. Neither is this the nature of vegetative changes, because the same sympathetic system is engaged in both kinds of behavior. Extensive muscular activity is not in itself responsible for the increased stability. Indeed, when the animals learned to inhibit their movements to avoid electric shock, ulcers were not found to develop in the gastrointestinal tract. On the other hand, when the animal was sub-

jected to electric shock regardless of its behavior, the ulceration positively correlated with movement intensity.

Our analysis suggests that self-stimulation and actively defensive behavior differ from passively defensive behavior in that they incorporate search, namely an activity aimed at changing either the situation or the attitude towards it. The results of this activity cannot be predicted but are used in subsequent analysis. Search is obvious in aggression and escaping when an attempt is made to overcome the stressing situation but success is by no means certain. In man the search manifests itself as planning or fantasizing or other kinds of psychic activity.

Passively defensive behavior amounts to giving up search when the situation is not to the subject's liking. In man this is the state of depression and hopelessness or a feeling of insecurity. Clinical observations confirm that many somatic diseases develop against this background.

These findings on search activities are also confirmed by the observation that the animals which tend to show actively defensive behavior under stress behave in an investigative and searching way to a larger extent than those which behave passively and defensively under stress.

Search and abandonment of search may also be observed in situations which do not lead to unpleasant emotions. The animal may continuously seek to reexperience the pleasurable sensations which is equivalent to self-stimulation. An individual who has achieved an objective and is satisfied with the situation can either set another objective (as is the case in creative activities) or stop striving. But it is precisely in the latter case that the Martin Eden syndrome develops. If, on the other hand, the individual attacks new, even very involved, problems, his health is preserved, even though he may experience failures.

Consequently, the main factor which influences the orga-

nism's stability is the nature of the behavior, the presence or otherwise of searching activity, rather than the "sign" of emotions. Unpleasant sensations which act as incentives of search are preferable to inaction. Stable positive emotions do not arise without searching activities. Cessation of search results in inability to satisfy the need and gives rise to the associated unpleasant sensations. If the need in search has not been formulated at the proper time, the low intensity of search does not necessarily entail negative sensations but the subject remains very vulnerable to various harmful stressors.

Searching activities are inborn and biologically beneficial but are not realized unless the training is correct. The need in search and the ability to search are formed at the earliest stages of individual development. Systematic failures at these stages (encounters with unsurmountable problems) result in reduced searching activities and, in adults, total cessation of search. The search may also be given up when the negative results of unsuccessful search become more significant and traumatic for the subject than failure in achieving the goal.

Even under extensive stress the stability stage is not necessarily followed by exhaustion; the latter probably does not set in before search is abandoned.

Cessation of search being harmful and dangerous for the organism, nature has devised protective mechanisms, of which rapid, paradoxical, sleep is the most important.

The night sleep is known to consist of several cycles, each starting with a slow phase and ending in a rapid phase. In the latter phase rapid eye movements (REM) are recorded, the tonus is reduced, the encephallogram is very much like that in wakefulness. Waking up from REM sleep, the subjects usually remember their dreams. The deep slow sleep (when slow eye movements, or SEM, are recorded) pre-

vails in first cycles while REM sleep dominates the final cycles. In higher animals the sleep pattern is essentially the same. Our own research and the analysis of the findings of others suggest that searching activity occurs during REM sleep in order to compensate for the cessation of search in the wakefulness prior to sleep and in order to restore the ability to continue the search after the awakening.

Many facts support this point of view.

When neurotic anxiety and depression make a subject discontinue all search, the need in REM sleep becomes more urgent. The time before the first episode of REM sleep is reduced and its duration in the first cycles increases. Following a passively defensive response to a natural stressor situation or to direct stimulation of brain structures, the REM-to-SEM sleep ratio increases.

The depressants such as reserpin and neuroleptics increase the duration of REM sleep while the antidepressants, drastically decrease it.

When the searching behavior is intensified in the wakeful state, be it actively defensive behavior or self-stimulation or highly creative activity, REM sleep is not needed so urgently and so the time to its first episode increases and its duration decreases.

In all animals whose searching behavior in wakefulness shows the characteristic theta-rhythm of the hippocampal brain structure, this rhythm is also recorded during REM sleep; the more pronounced this rhythm in wakefulness, the less pronounced it is in REM sleep, and vice versa.

Other arguments in favor of this mechanism are the findings of M. Jouvet and A. Morrisson, who studied the behavior of animals in which the brain zones controlling the weakening of tonus at this stage of sleep were destroyed. The animals acted as participants of their own dreams; they got up, sniffed and looked around with their eyes closed, ran

short stretches and jumped in imitation of pursuing inexistent prey or escaping inexistent danger. Both Jouvet and Morrisson emphasize the pronounced searching component in this behavior. In private communication to this author Morrisson has described results confirming this role of REM sleep in restoring the searching activity.

Searching activity and inaction are incompatible. Therefore increased searching activity in wakefulness or during dreams facilitates overcoming the consequences of inaction. REM sleep makes the decisive contribution to maintaining physical and mental health. Many researchers noted that depriving the subjects of REM sleep by repeated interruptions results in increased neurotic anxiety. If REM sleep is disturbed and fails to perform its functions, the subjects develop various pathologies. Indeed, in some psychosomatic patients the number of dreams is below normal and the vegetative activation is less pronounced.

The length of REM sleep during the night and the intensity of activities in the subject's dreams may probably give an insight into the subject's health and the quality of his emotional state in wakefulness.

In conclusion let us discuss some possible biochemical mechanisms of searching activity. There is strong evidence that its extent depends upon the amount of biologically active catecholamines, notably noradrenaline, in the brain and also upon the sensitivity of some brain structures to these substances. The passively defensive behavior and somatic disturbances in laboratory-invoked stress do not start in the animals unless the brain catecholamine level has been reduced. If drugs prevent this reduction, the stress-immunity increases and it is more difficult to compel the animal to halt searching activities.

The data on the interdependence of REM sleep and the catecholamine system is very inconsistent. What is certain,

however, is that the dependence is nonlinear. When this system is very active the rapid phase diminishes. A mild reduction of this activity entails an extension of this phase, but a pronounced reduction leads to inhibition of this phase. Many contradictions are overcome by accepting the following hypothesis.

1. The catecholamine exchange in the brain proceeds differently when search is under way and when it is abandoned. The faster the catecholamine consumption in search, the faster the synthesis. The searching activity probably dictates the type of catecholaminergic neurons or prevents the inhibition by an enzyme which regulates the synthesis. This model resembles positive feedback, namely, the consumption of catecholamines, which act as the "fuel" for searching, is more than offset and there is no need in other replenishment mechanisms.

2. If search is given up, this positive feedback is disrupted. The catecholamine consumption ceases to stimulate the synthesis; the normal exchange is restored through "compensating" search in REM sleep which, like any other search, accelerates the synthesis.

This hypothetical mechanism accounts for the difference between the two ways of search termination, i.e., unproductive anxiety and depression. The anxiety reflects the continuing depletion of the catecholamine stores in the brain; the depression results from depletion below a certain threshold.

3. The searching behavior is "triggered" by a certain initial level of the catecholamine concentration below which searching is out of the question in both wakefulness and REM sleep. In natural conditions the search probably halts before this level falls to a critical value and so by the time sleep sets in the level stays above that critical value and compensating search is feasible in REM sleep. On the

other hand, in falling asleep the individual temporarily extricates himself from the situation which made him halt the search because the brain catecholamines were in short supply. This extrication facilitates the restoring function of REM sleep.

If, however, extensive inaction reduces the catecholamine level below the critical threshold, the "triggering" of compensating search in REM sleep is impossible. This is the reason behind the nonlinear dependence of the activity of the catecholamine system on REM sleep, nonlinear in the sense that with high activity (pronounced search in wakefulness) the need in REM sleep decreases; with moderate reduction of the activity the need in REM sleep is increased; in the case of inaction the functional potential of the most rapid phase of sleep is depleted. In other words, brain catecholamines are essential for REM sleep to perform its functions, while REM sleep facilitates the resumption of searching.

In effect, the mechanism of search activity explains within the framework of one feedback mechanism the changes occuring in the organism on very different levels, from the psychological to the biochemical, and sheds a new light on many old problems.

References

1. Selye H. Stress without Distress. J. B. Lippincott, 1974.
2. Olds J. Drives and reinforcements: Behavior studies of hypothalamic functions. Raven Press, New York, 1977.
3. Вайнштейн И. И., Симонов П. В. Эмоциональные структуры мозга и сердца. М.: Наука, 1979.
4. Вальдман А. В., Козловская М. М., Медведев О. С. Регуляция эмоционального стресса фармокологичскими препаратами. М.: Медицина, 1979.
5. Seligman M. E. P. Learned helplessness and life-span development. In: Proceedings of the International Conference on Life-Course Reserves of Human Development, 16-21 Sept. 1982, West Berlin. Max Planck Inst. West Berlin, 1982.

On Man's "Third State"

V. I. KLIMOVA

As far as data processing in medico-biological applications is concerned, man's "third state", when he is neither healthy nor sick, is inseparable from the large-scale system made up by man and his health.

This approach makes it possible to view man from both "inside" and "outside"; to unravel the intricacies of his fitting the environment; and to detect the dynamic constancy of the organism's instabilities and the harmony of its constant mobility. Health as a field of research is not divided into components that are to be treated by specialized disciplines. Rather, different flows merge, what is discovered and understood by different sciences is synthesized; the entire variety of functions, structures, and links make a large-scale system of man and his health.

Any large-scale system possesses four basic qualities [1].

(1) It is a most complicated set of interconnected elements. Thus man's health depends on the interaction, mutual causality, and interrelationship of various elements and factors.

(2) Any large-scale system interacts with its environment. Man's health is inseparable from the environmental conditions which make beneficial or adverse impacts on him.

(3) Any large-scale system is a component of a larger system. Thus man's health depends on a more complicated system which is society; it is obviously an integral part of life on the earth and probably in the universe.

(4) The elements of a large-scale system are lower-order systems. The "third state" is one of subsystems of the "man's health" system.

Much attention is given now to the "third state" because too many people stay in it for months and years.

Neither Health, Nor Sickness

Health and sickness are opposite states of the organism, and can be described in quantitative terms. But it would be a great mistake to think that man is either in the one or in the other state at any given time. Health and sickness are more like two ends of the spectrum rather than two polarities. This uncertainty when no sickness is obvious but the individual is not in good health is referred to as "the third state". In all its various forms the feedbacks are disturbed either in the functioning of the organism's internal systems or in the interaction of internal structures and the environment.

There are several kinds of "the third state".

In one the organism is healthy but functions in a changed state which is normal for the specific period. Such are the puberty period in adolescents when the organism takes on additional endocrine and nervous loads; mother's pre- and post-natal periods; and healthy old age. In all of them deviation from normalcy is normal.

In all these instances the restructuring of feedbacks is triggered by changes in the interaction of intra-organism structures.

Another kind is adaptation, which may take a fairly long time, to extreme environmental conditions such as those in polar, tropical, arid or wet regions. A similar pattern is observed when people acquire new skills or have to work in new environments or take on increased committments which require added physical or, more often, nervous strain. Old feedbacks are restructured and new ones are built in response to changes in the environment.

An individual who has not adapted to the environment, natural or industrial, is twice the loser, for he (or she) exerts more efforts than the other for the same kind of work but can-

not work efficiently. For this reason a reduction of the number of people in "the third state" may increase the labor efficiency.

All these cases are either inevitable or dictated by circumstances. Some, quite a few, people, however, choose the third state. They gradually drift from health to sickness. These are, in particular, all smokers and drinkers who break the interaction of the organism's systems and elements by imposing a pathological mode of life where the internal data transmission paths are changed.

In all events, "the third state" is adaptation whereby new outputs are generated in response to new inputs. If the response takes too long, if the organism is "inflexible", "the third state" is very likely to start.

Adaptability is a form of stability; the physiological mechanisms are stable in that they work to achieve normalcy. They comply with the wisest law of nature, the law of self-regulation. Deviation from the normal pattern is the reason for the interactions to return to normalcy. This return is made possible by the wide safety margin of the living beings in which the sum of all actions returning the organism to normalcy is larger than the sum of all deflecting actions.

In Pavlov's words, "The human organism is to the highest degree a self-regulating system, which directs, maintains, restores, and even improves itself" [2].

Centuries-Trained Duet

Food may be largely responsible for "the third state". Its contribution is enormous in that it is the source of vital supply for (1) growth and restoration; (2) energy storing; (3) regulation of processes by biologically active substances.

Recently the immunity was also found to depend on the food quality.

Exchange of matter with the environment is essential for the organism. Undernourishment or overnourishment are bound to have a harmful effect on the organism regulation.

It is because of its great significance for life that food may be responsible for man's entering the third state. There are several intertwined reasons for this.

One of them may be referred to as evolutionary.

In his book "The Part Played by Labour in the Transition from Ape to Man" Engels noted the importance of the chemical composition of food [3]. He described the entry of various substances into the organism as "the chemical conditions" for the process of the making of man. Stable chemical environment used to exist for millions of years and has abruptly changed within the lifetime of two or three generations. Over the last ten decades or so the amount of natural food in people's diet has fallen dramatically.

Another reason may be referred to as energetic.

Food is the fuel from which the organism obtains the energy. Therefore, the nutritional value is defined as the amount of heat in calories obtained by burning the foodstuff. The more man works, or the more physical effort he exerts, the more calories he burns.

But the human organism is not merely an "oven" to be filled with any fuel. Dietologists emphasize the need in a balanced, various nutrition. It is conceivable that foodstuffs transmit signals which are essential for regulation of the organism.

In cybernetics all physical bodies contain information which reflects the measure of the variety, or complexity, of their internal structure [4]. This information is referred to as structural. Why not measure the difference in the complexity of the chemical structure of the foodstuffs? It would be only fair to assume that the information content of the

foodstuffs is very important for their consumers. Consequently the structural information may be a general characteristic of food in the same way that energy is.

In this light the "nutritional" information may be useful and harmful, insufficient, redundant, or optimal.

Another possible cause of "the third state" is shortage of physical exercises.

The all-important contribution of body movements to generation and expansion of adaptability in living beings is widely known. Man needs muscular, as well as intellectual, activity. During the evolutionary period the optimal ratio of energy arriving with food to energy utilized in physical activity was optimized. Furthermore, the brain is by no means indifferent to exercise or its absence. The data processing and control "center" is accustomed to receiving and processing signals from the muscles. If this information is in short supply, the brain activity is also reduced.

If it does not exert physical efforts to its utmost capability, an organism withers. What happens is again the disruption of the links which regulate the life support. This situation is conducive to "the third state".

Sleep and Dreams

Since "the third state" may stem from disorders in the most important functions of the organism it is not surprising that the sleeping habits and the balancing of the wakefulness-sleep cycle have a certain bearing on this state.

The five well-known phases of sleep and the four thresholds of its depth may be roughly classified into deep sleep and paradoxical sleep.

The surprising thing about paradoxical sleep is that the individual is unconscious while the brain is engaged in vi-

gorous activity; the muscles are completely relaxed while the metabolism is intensified. Every 80 to 90 minutes deep sleep alternates with paradoxical sleep. The first paradoxical period is the shortest, about nine minutes. Later in the night such periods become longer and may take as much as 30 minutes before the awakening. These periods total one hour and a half to two hours.

Dreams occur during paradoxical sleep.

Dreams are experienced by everyone. Although some people forget them they are essential in life support. This conclusion was suggested by numerous experiments in which the subjects were awakened when their eye movements indicated that paradoxical sleep began. If people were deprived of this phase of sleep they become irritable, restless, and incapable of concentrating on any particular thought. By their general indisposition the subjects remind of people in "the third state".

Some findings of this kind of research are challenging and intriguing. During the night the dreams are like variations of a theme. The shortest dream is like an overture and reflects, on most occasions, what the subject thought when awake, and contains the themes of subsequent dreams. The second and third dreams are usually about the past but their emotional coloring is dictated by the present in that the events in the dream are accompanied with relatively recent sensations. The fourth dream is, as a rule, a preview of the future where some wish is fulfilled. The fifth, the last in the night, is a composition of fragments of the previous dreams which are, in a way, summarized.

The dreams may be black-and-white or multicolored. The latter is, on most occasions, the case of more emotionally motivated people while the former, of "the rationalists". The dreams thus seem to be consistent with the mentality and activities of the subject. Thus the artists who deal with

colors tend to have multicolored dreams. Quiet well-tempered people tend to have dreams in cold tones, indigo, blue, and green. Red in their dreams is a signal of anxiety.

The relationship, in terms of data processing, between wakefulness and sleep, which is obvious in day-to-day life and is confirmed in scientific experiments, proves that sleep performs an adaptive function. There are, however, several interpretations of that function.

According to the data processing concept [5], the brain needs a break in its activity. In sleep it disconnects from the environment to process the information it has received during the wakefulness. Dreams then rank the actual events by importance.

When one is asleep the brain continues the thinking process. The information is rearranged, the signals are stored in memory, the important data is transferred from short-term to long-term memory. As no new information arrives in sleep, the memorization of the accumulated data is enhanced.

Another interpretation is the so-called search hypothesis which combines in a cybernetic mechanism the emotional type of human behavior, man's ability to withstand nervous strain, and sleep [6]. During paradoxical sleep a search is believed to take place. It offsets the biologically adverse consequences resulting from indecision in wakefulness when some individuals behave passively in response to emotional disturbances. In one's sleep the brain looks for a solution.

This theory is supported by strong evidence. As mentioned above, if they are awakened during paradoxical sleep, healthy individuals grow worried and restless. Another fact is the dependence of the duration of this phase on the psychic state and behavior in wakefulness. If an individual is active, the paradoxical phase is stronger.

This dependence is confirmed by observations of people who need little sleep and those who need a lot of it. The for-

mer feel and work well after five to six hours of sleep while the latter need at least nine hours. The former are vigorous people who willingly meet challenges and do not concentrate on displeasing experiences. The latter are emotionally very sensitive and need long sleep to prevent anxieties and depression take root in their consciousness and disturb their mental health.

The search for a decision or a resolution of conflicts in one's sleep is performed by "reexamination" of the actual situations in one's dreams. If the opposing motivations "reconcile" in the language of dreams, the conditions leading to restlessness or wear cease to exist and normalcy is maintained. When more time is available for the "negotiations" in one's dreams, the chances for constructive solutions increase.

In any case, sleep is known to be an important factor in man's health and, consequently, in overcoming "the third state".

In effect, if "the third state" is viewed as a lower ranking system in the complex system of man's health, the data processing models give an insight into the most important links in control of the organism's functioning.

References

1. Chestnut H. Systems Engineering Tools. John Wiley & Sons, Inc., New York, 1965.
2. Павлов И. П. Полное собрание сочинений. М.: Наука, 1951, т. 3, кн. 2.
3. Marx K., Engels F. Collected Works, Progress Publishers, Moscow, 1975, 1976.
4. Брехман И. И. Человек и биологически активные вещества. 2-е изд. М.: Наука, 1980.
5. Вейн А. М. Три трети жизни. М.: Знание, 1979.
6. Ротенберг В. С. Адаптивная функция сна. М.: Наука, 1982.

III. Difficulties on the Road to Truth

Science and New Information

Road to Truth (on the scientific method of cognition)

A. B. MIGDAL and E. V. NETESOVA

What is truth? This question always has been and always will be fascinating mankind. Countless answers were given to this question. In fact, they were all indirect: Truth was portrayed as a greater friend than even Plato himself; some looked for it in wine, and others at well's bottom; the illustrious and cruel Pontius Pilate, who mastered all the wisdom of the antiquity, condescendingly put this question to a beggar philosopher whose lot was to die a cruel death; Leo Tolstoy tried to find the answer all his life... Can it be that the purport of the question lies in the infinite search for the answer?

Our purpose here is much more modest. We are going to discuss one particular case, namely, that of the objective scientific truth which can be discovered and which every one must learn to recognize and not to confuse with lies and delusions.

Misconceptions are exceptionally long-lived; the attractiveness of the mysterious and the unusual, a thirst for miracles are inherent in human nature. Our nature hardly changes with time: as early as in the 16th century Montaigne explained how miracles were born. His words are as relevant

now as they were four centuries ago: "Now the first that are embrued with the beginning of strangenesse, comming to publish their history, finde by the oppositions made against them, where the difficulty of perswasion lodgeth; and goe about with some false patch, to botch up those places. Besides that, *Insita hominibus libidine alendi de industria rumores*: *Men having a naturall desire to nourish reports.* We naturally make it a matter of conscience, to restore what hath been lent us, without some usury and accession of out encrease. *A particular errour doth first breede a publike errour*: And when his turn commeth, *A publike errour begetteth a particular errour.* So goeth all this vast frame, from hand to hand, in such sort that the further-abiding testimonie, is better instructed of it, than the nearest: and the last informed, better perswaded than the first" [1].

Nowadays the flood of information brings to us numerous nonverified facts and rumours. Pseudoscientific speculations cannot be banned, lest they gain the attractiveness of a forbidden fruit; but they can be fought by popularizing the true science.

One is able to find his way in the seas of modern scientific ideas only through mastering the scientific method of cognition which is the subject of this paper. The accumulated experience of science-popularizing lectures and discussions, as well as the lessons of letters sent in response to paper articles and TV talks indicate that people having little to do with science, and even some journalists writing about science, do understand scientific ideas but are quite hazy about the scientific method which is the only tool for perceiving the objectives of science.

The question of whether one can regard as true what he sees with his own eyes troubled man ever since the most ancient time. After numerous experiments the sages despaired of overcoming the monstrous contradictions in witnesses' acco-

unts, and at last chose to abandon all attempts to find out anything; they declared that nothing could be stated irrefutably, even that "snow is white" (because "if I declare it to be black, nobody will be able to disprove this statement"), nothing could be understood, and whatever was considered true might prove to be a lie. This dreary philosophy had remarkable longevity, despite the ridicule addressed to it by the foremost thinkers believing in the all-powerful human mind: the problem of comprehensibility of the world and of the reliability of knowledge remained as a menacing obstacle for the incipient natural sciences.

The scientific method of cognition matured only at the beginning of the 17th century and ever since it formed a firm basis for the progress of sciences. The scientific method is the compass which enables us to find among thousands of paths the only road that leads to truth.

This road begins in keeping with the tradition, i.e., by forking out into three paths. One path leads to what certainly exists, another to what cannot be. It is thus necessary to delineate the domain of the certain from the domain of the impossible. This can be done owing to the stability of scientific achievements.

Science is stable in that new results do not cancel older ones: neither relativity nor quantum theory invalidate classical mechanics or classical electrodynamics; the new geometry predicted by Einstein's theory of gravitation and verified by observations does not invalidate the old Euclidean geometry. One of the fundamental methodological principles of science, namely, the correspondence principle, states: a new theory must convert into the old one under conditions in which the latter was established. The new theory defines these conditions more rigorously, establishing the bounds on the applicability of the older theory.

The stability of science, i.e., irrefutability of thoroughly

verified laws, makes it possible to relegate to the domain of the certain all that cannot be refuted whatever the turn in the evolution of science.

We know that the Earth is round, that the law of energy conservation cannot be crudely violated, that no material object can move at a velocity exceeding the speed of light... This certainty of knowledge is the basis on which physicists found their sceptical attitude toward the possibility of moving a material object by "a spiritual force", i.e., be telekinesis. Should it be possible, the tiny roulette ball would invariably stop at a lucky number since it would be controlled by the strong will of the gambler, and the lightest objects with which physicists work would follow the most fantastic trajectories imposed by the experimenter burning with a desire to make a discovery.

However, scientists are attracted not by these roads to the certain and to the impossible; science conducts its search on the third, middle road which passes through the region of possible but unknown, bounded by the certain and the forbidden.

Consequently, while refusing to accept the possibility of "willing" a material object to move in space, physicists avoid categorical statements when somebody mentions communication from one mind to another through some known or yet unknown fields, provided any other contact between the inductor and the recipient is suppressed (something given a captivating name "telepathy"). When a specialist says that so far no scientific proof of telepathy is known, he means that in spite of numerous attempts, no reliable experiments were carried out that would exclude all alternative explanations and provide reproducible results with conclusive statistics. Hypnosis requires a contact between people, so that neither is it subsumed under the definition of telepathy nor its existence is proved.

Science would only gain from an unbiased study of such phenomena as telepathy: not from attempts to prove or disprove it, but from thorough analysis of all possible types of interaction between people, beginning with physical fields surrounding man. No doubt that a reader of science-popularizing articles will immediately recall the "biofield" called forth to explain all sorts of miracles. However, let us specify our terminology: we shall define biofield as a field not detectable by physical instruments and produced only by living beings, perhaps only by beings endowed with reason. Physical fields generated by human body are not different from fields generated by other sources. For instance, electric fields around a man and around a condenser are virtually identical. These fields were a subject of scrutiny over a considerable time. It is clear that these fields are appreciable only in the closest proximity to human body, being very weak even at a distance of several meters and hopelessly disappear in the sea of noise fields at a distance of a kilometer or more. The transmission of thought or images over considerable distances by means of physical fields is thus impossible, unless some yet unknown biofields are involved.

Recently a research program aimed at studying all physical fields surrounding a human body was started by modern experimental techniques, using the most accurate physical instruments. Thus, a Corresponding Member of the USSR Academy of Sciences Yu. V. Gulyaev and E. E. Godik, D. Sc., conduct such a research program at the Laboratory of Biomedical Radioelectronics of the Institute of Radio Engineering and Electronics of the USSR Academy of Sciences. The work is done at such level that hardly any physical field will escape the scrutiny of scientists.

As for the biofield, it stands in contradiction with the expectations of modern biophysics, and so far there is no ground for believing in its reality. All serious attempts to

confirm the existence of biofields have failed. Nevertheless, the search for biofields, guided by scientific method, may prove to be very valuable, even if the main result is negative.

The road is thus chosen, and we move along the path of the unexplored, i.e., of the possible but not yet discovered. It is very important to separate unhesitatingly the most elegant, the most romantic, even the most plausible guesses from proven statements. Science needs this approach as much as criminal law does: the former in order not to be smothered by superstitions, the latter in order not to lend support to lawlessness.

The jurists of Ancient Rome based their verdicts on the presumption of innocence: the accused was considered innocent until his guilt was proved. Likewise, scientists cannot be held responsible for the lack of explanation of strange and incomprehensible phenomena until romantics prove that these phenomena are real. Before asking a physicist why, in contradiction with accepted knowledge, do flying saucers move at a speed greater than the speed of light, it is necessary to prove that a flying saucer is a material object and not a sunbeam.

In all contingencies, and especially on the road to scientific truth, the best advice will be given by a specialist.

The ultimate professionalism is one of the basic requirements to a person devoted to science. Is this statement true to facts? Indeed, it is common knowledge that Ampere and Faraday had no special education, Volta studied at a Jesuit school, Joule was a brewer, Copernicus, Helmholtz and Mayer were doctors, Avogadro, Lavoisier, and Fermat were lawyers... Even in our time, when each field of science is extremely specialized, many such examples can be found. In literature the situation is obvious: a writer with special

education is a rarity. However, these examples lead to a misconception which complicates the issue of professionalism and dilettantism. It is a misconception indeed, because people citing these examples from history of science tend to forget that all of the above-enumerated "dilettanti" achieved success only after having grown into the most knowledgeable specialists in the new fields, having mastered the secrets of the new professions, i.e., having re-educated themselves.

The ideas that pass the test of time were invariably conceived by professionals. The scientific intuition itself gets shaped only through hard professional work.

Our road to scientific truth will be facilitated if in dubious cases we turn to the opinion of specialists. Having listened to the stories about Philippine healers who dip an unwashed hand into the patient's belly and pull out the appendix, after which no trace is left on the body, we put a question to a surgeon and find out that tissue regeneration takes seven days and that a miraculous regeneration within a second is sheer baloney. The surgeon will advise us to ask a conjurer; a top-grade conjurer will cut a woman into pieces before our very eyes and then assemble her anew leaving no traces. "No traces" means "no cuts"! Questions about flying saucers must, therefore, be addressed to specialists in atmospheric optics, questions about the Loch Ness monster to zoologists and oceanologists, just as in cases of faulty wiring we invite an electrician and just as toothache drives us to a dentist.

In certain areas of human activities, the common sense is of paramount importance. Here a layman can sometimes take issue with a professional. Is it possible that dilettante suggests an original design prompted not by knowledge but by intuition, by a vague association that the specialist overlooked? Yes, of course, a man whose legs got numb in an

airplane may invent a new, comfortable shape of a seat for air travel. But he will suggest new plane design only after having learnt, in the course of work, all professional subtleties, the laws of aerodynamics, physics, chemistry, engineering, and technology, i.e., after he becomes a highly skilled specialist, even if he does not notice it.

The probability for an uninformed to come up with a profound scientific idea is as low as the probability to jump into your boots off a bell tower. Perhaps, science is helped by science fiction? Was the fairy-tale flying carpet helpful to designing a modern liner? Likewise, was engineer Garin's hyperboloid a help to the developers of the laser? There is also another idea which, unfortunately, is encountered quite frequently on the pages of current science-popularizing magazines: isn't it possible to find the principles of, say, relativity in ancient myths?

First-class science fiction has other aims to prompt scientists. Alexis Tolstoy was quite indifferent to laser design, he was thinking about the behaviour of a man who got hold of such a powerful weapon. Science fiction is a phenomenon of culture, not a method of seeking scientific truth, and this is perfectly clear to the best SF writers.

The flying carpet is a triviality prompted by actual life whose cues are never straightforward. Karel Čapek had this to say about the relationship: "An aircraft no more resembles a bird than a torpedo resembles a trout. Should man set out to design and construct a flying bird, I bet that his creation would not fly. No doubt, man did want to fly as birds do, but he achieved it by devising something else: propeller design. In order to swim underwater as a fish, man had to invent the internal combustion engine and ship's screw, instead of imitating the fins of a fish. ...This is what makes inventions so unpredictable and so paradoxical" [2]. The flying carpet is a marvel of human fantasy, a bird is

a marvel of nature, and the giant aerobus is a marvel created by human hands and human reason.

If the theory of relativity is reduced to a sagacious statement "everything in this world is relative", then supportive phrases can obviously be found anywhere, beginning with Iliad and ending with kid's counting-out rhymes. Something that was later confirmed by the development of science can always be angled out of the sea of vague and fortuitous statements. In fact, a general idea becomes valuable for science only when it is supported by scientific arguments. As for these arguments, they are the realm of professionals.

Experts are readily, and mostly unjustifiably, accused of being too limited, incapable of discovering the unexpected. This, however, is true only with respect to mediocre specialists. Those who are at the frontlines of science cannot allow prejudice to influence them. They are indeed restricted by what they know but to a reasonable extent: a scientist steps beyond the accepted concepts only when the new outlook does not contradict the established facts. Dilettanti do not have to comply with the facts because, among other things, they are unaware of these facts. They are completely unbiased, resembling a baby for whom the complexities of the surrounding world are nonexistent.

A condescending and contemptuous attitude towards specialists is akin to another regrettable but widespread phenomenon, encountered even among specialists: the tendency to disparage a genius.

The most certain way to degrade a personality is to soil his creation. Writers, composers, artists, scientists are accused of borrowings, as if it is possible to create something from nothing; the authorship of Shakespear's sonnets and tragedies is attributed to most various people, including Queen Elisabeth; "Requiem" is said to have been written not by Mozart but by his pupil... How tormented were Gali-

leo, Pushkin, Wagner, Boltzmann, Lobachevski; what moral cost was it to Einstein to defend himself from foolish cavilling and accusations... People "in the know" do not leave great creators in peace even after their death. A handful of physicists still hold that relativity was created before Einstein by Henri Poincaré. Their only excuse may be the argument that they hardly realize how physical theories are constructed.

The great French mathematician Henri Poincaré and the young Einstein sent their papers for publication in 1905, almost simultaneously, so that Einstein could not know anything about the yet unpublished Poincaré's paper. Furthermore, the 24-year-old expert of the Bern Patent Bureau, head of a family, who was pondering relativity while taking out for a walk a perambulator with his child, knew nothing even about the work of the Dutch physicist H. A. Lorentz, published in 1904; Poincaré's paper was a continuation of Lorentz's work.

Poincaré's paper which enormously affected the whole of theoretical physics, dealt only with electrodynamics, just as Lorentz's paper did. The point lies, though, not even in the priority angle. Lorentz and Poincaré did obtain almost all important relations of relativity, but the meaning of these relations, their applicability to all phenomena in nature became clear only after the dramatic change in conventional concepts of space and time that Einstein introduced. This is the most important element of relativity. Physics is not so much the formulas as the interpretation of formulas.

Those who write about science must remember, whether they write a popularizing article, a philosophical essay, or a biographical novel, that disrespect to the heroic achievements of human mind may infect young scientists at the start of their creative life with cynicism that will render stillborn their craving for discovery.

Einstein's picture of science was: "This is a drama, a drama of ideas". Writers, playwriters, scriptwriters frequently forget it or, perhaps, are simply unaware of this facet. Movies and books too often describe for us the events external to the life of a scientist. Did you ever try to narrate exactly the events in a Dostoevski's novel, say, "Idiot" or "Karamazov Brothers"? The whirlwind of events, a most complicated plot remains almost unnoticed by the reader, so much they are upstaged by the overpowering drama of ideas. When retelling the novel, you retell ideas, not the plot. Events are necessary to the author only for presenting an idea in a new light, in a new context... For example, the plot of a good movie, "Nine days of one year" would boil down in retelling to saying that one scientist died because he disregarded safety rules, and the other came down with a serious illness having first spoiled the life of an attractive woman.

A life devoted to science need not be sacrificed for making a discovery, unless this discovery may save mankind from a terrible disease or a direct threat of extinction. In an extreme case a doctor may test a plague vaccine on himself, at a risk of dying of this horrible disease, but in normal conditions a scientist must regard his life as society's asset, which may prove to be instrumental in leading to future discoveries. We should not expect that a scientist will rush into the reactor and make a discovery. He is a bad aircraft designer who botches the undercarriage design in the hope that valiant pilots will be able to crash-land the plane on its belly.

We anticipate a "such-are-the-rules-of-the-game" counterargument. A story about a physicist who decided to stay within a reactor in order to witness a nuclear reaction is much more entertaining than a story about a man who locks himself in a study and writes night and day numerous ab-

struse formulas. One can only narrate about this protagonist how he confused salt with sugar, or how he carried the spoon past his mouth. To describe how a scientist is born anew, lives, and dies many times together with each new idea is very difficult because the writer has to understand how an idea is born, lives, and dies.

To popularize science is a necessary, noble, but extremely demanding task. The Danish philosopher Sören Kierkegaard wrote: "Christians talk to God. Philistines talk about God." This beautiful mystic proposition will help to draw a parallel. Two types of science popularization are possible. The first, which brings easy success, is simple, effective, and more frequently encountered; it amounts to speaking about science-related topics, about practical applications of science. The second is to speak about science, and is achieved only by true masters.

To single out the quintessence of an idea is a task for an expert scientist. Unfortunately, specialists often regard such work as a waste of time, and their time is precious. Actually, this work is helping not only the readers but the scientists themselves as well. In contrast to art, in science a profound idea only gains from a simplification.

A writer popularizing science must act as a translator, a conductor, an intermediary between a scientific idea and a non-scientific reader. Even if the author is a specialist and thus knows what he is writing about, his popularizing will not avoid difficulties. One of the obstacles are the multivaluedness of concepts and the paucity of our very rich language. Numerous hues of meaning, inherent in a word, result in repeated distortions, and the discussion unexpectedly changes emphasis. Let us take the definition of the word "jump" in the Soviet Encyclopaedic Dictionary: "Drastic change in the evolution, qualitative transformation of an object as a result of quantitative changes." If, however, a scientist says

that nature manifests no jumps, this means that all processes are continuous in time, and even quantum jumps (e.g., jumps of electrons from one orbit to another) proceed continuously; being very small, they are practically unnoticeable. Only a reasonable idealization allows us to speak of jumps in nature because experiments yield separated points to which a curve is fitted in the belief that physical processes are continuous. But an interlocutor for whom "jump" has a philosophical meaning (i.e., a jump in concepts, not in physical quantities) objects, overlooking an unintentional overstatement: "a revolution is a jump, the pioneer space flight of man is a jump..." This is obviously only one example out of many: there are numerous concepts which in a stereotype conscience are immediately transposed into a different field, thus producing doubts and a suspicious attitude towards science.

Owing to this confusion of concepts, even a conscientiously written popularizing article can produce a distorted picture. This is all the more true for numerous publications delving into strange and incomprehensible phenomena. Aglaya, one of the protagonists in Dostoevski's "Idiot", declares that a lie becomes significantly more plausible if the liar adds to it something absolutely unbelievable. For instance, we may read that a plane flying through the infamous Bermuda triangle towards Miami disappeared from radar screens for ten minutes, neither the passengers nor the crew having noticed anything strange. A wary reader is not impressed: "Faulty radar..." However, when he is told a deadly detail—all clocks and watches in the plane were later found to be ten minutes behind true time—he begins to doubt his disbelief no matter how sceptical he was.

Do dubious, speculative articles deserve being printed? Yes, they do, but on the condition that they be accompanied by a comment, written by a qualified specialist: dubious

statements must be countered with a positive program of disseminating true knowledge.

We conclude, therefore, that the road to scientific truth is gained by strictly separating the domains of the certain and the impossible, relying on expert opinion, and distinguishing between guesses and proven statements.

The main tool of the scientific method is the experiment. Truth is established by conducting a scientific experiment yielding repeatable results and supported by independent experiments of other scientists. This requirement of repeatability and reproducibility of results is the *sine qua non* of science.

Specific problems of a specific science dictate the peculiarities of experiments. An astronomical experiment consists in choosing the place, time, and method of observation in a special way. Mathematicians make plausible hypotheses, i.e., experiments which are subsequently transformed into proofs. Experiments required in biology and psychology are often not quantitative but qualitative; nevertheless, such experiments can reveal the degree of generality of relationships, and from this a law. The experiment is not observation, it is a pressing question addressed to nature and assuming that an unambiguous yes-or-no answer is possible.

"To me, one thrilling falsehood's dearer
than hosts of uninspiring truths..."

These Pushkin's lines are frequently quoted in talking to scientists. Pushkin, however, chose the word "lowly" for these truths as the most correct one. His pithy phrase is aimed at such cliché statements as "charity begins at home", "a bird in the hand is worth two in the bush", etc. In contrast, the truths that enrich our understanding of nature run as a clear stream through a turbid jumble of false miracles.

In the spirit of the rule recommended above, let us turn to an expert for an opinion; and who is a better judge in a debate about truth than Dostoevski whose entire life was a search for truth: "...truth, and above all truth in its purest state, is the most poetic thing in the world; more than that even, nothing that the smart human mind could concoct or conjure up is as fantastic as truth..."

References

1. de Montaigne M. Essayes, London, 1890.
2. Чапек К. Собр. соч.: В 5-ти т., М.: Художественная литература. 1958, т. I.

The Dynamics of New Truths in Biological Sciences

S. E. SHNOL

As in other sciences, recognition of new biological knowledge has been a complicated process occasionally taking unexpected and tortuous twists. The facts and ideas which disprove the existing views are usually ignored and remain unexplored for a long time. A delay may be very costly for science and its application. It is enough to mention belated recognition of the role played by nucleic acids in the transfer of hereditary information, the membrane mechanism of cell excitation, and the modeling of biological processes in cybernetics.

Let us try to understand what is behind these delays.

The Classical and Stochastic Determinism in Biology

The Newtonian mechanics instilled in all sciences the "classical determinism" which implied unambiguous causal links between natural phenomena. For the sciences of late 18th and early 19th centuries this view was constructive because it supported rationalism (from Latin *ratio*, reason) which asserted that reason could master the laws of nature, in particular, reveal the causal links between natural phenomena.

Lamarckism was an outgrowth of the classical determinism; it considered biological evolution as the outcome of certain causes; the inheritance of features was believed to be directly influenced by exercising (or not exercising) an organ (mechanolamarckism) or by the desire to perform a given function (psycholamarckism). This theory was constructive in its time in that various biological phenomena could be viewed from the same angle while basic principles could be experimentally tested. The Lamarckian rationalism supported the belief in the potential of human reason. This accounts for the survival of the theory long after it was made hopelessly obsolete by Darwin's theory which in turn resulted from profound changes in the general scientific paradigm.

The probability theory came into existence in the late 18th and early 19th centuries. It predicted the consequences, such as the mean, variance, etc., of a set of random events, or causes; the accuracy of this prediction increasing with the number of these events. While in the classical determinism the consequences become more certain and predictable as the number of their causes decreases, in the stochastic determinism the consequences are predicted more accurately as the number of their random causes increases.

Darwin's theory explains the natural phenomena in terms of stochastic determinism. Indeed, the set of random events in the interaction of living beings with one another and the environment results in natural selection whose certainty increases with the number of elementary events in the system. By 1859, when "The Origin of Species" was published, the scientific community had embraced the ideas of stochastic determinism. That was the reason why Darwinism was recognized so widely and so fast and caused such resonance.

Changes of general scientific concepts make an impact on various fields of science.

Stochastic determinism was the very core of Wiener's "cybernetics", the science which tackles most various problems in the "probabilistic universe" where life is a major component. Cybernetics also brought to the fore the ancient concept of atomism, or discreteness. Other founding fathers of this new science of control and information processing, notably John von Neumann, emphasized the discrete mathematical tools of cybernetics which were amplified with the advent of digital computers.

Incidentally, the discreteness had been incorporated into the general scientific picture of the world after 1900 when Planck discovered energy quanta.

Had the idea of discreteness been digested earlier, sciences, especially biology, would have grown faster. The theory of evolution could not develop unless the carriers of hereditary information were discrete, because, otherwise, as shown by F. Jenkine, every new trait, resultant from non-deterministic variability, would be dissolved in subsequent generations and gradually fade away. This thought was a nightmare for Darwin. But in 1865 Mendel published his now famous paper which showed that the genes, discrete carriers of traits, did not fractionalize and so Jenkine's objection was re-

futed. But because a discrete inheritance mechanism was difficult to visualize, Darwin did not accept Mendelism and could not overcome the problems of his own theory. It was not until 1901 when Planck's discovery became widely known that Mendel's finding were "resuscitated" by H. DeVries in the Netherlands, C. Correns in Germany, and E. von Tschermak in Austria. The marriage of theory of natural selection to the genetic theory whereby discrete genes encoded the traits to be inherited brought to life the today's genetics, molecular biology, and their agricultural and medical applications.

Proteins versus Nucleic Acids

The discovery of protoplasma was a major breakthrough of the last century's biology. The substance of all cells, protoplasma, was regarded as the life substance. The term "living protoplasma" was widely used. Protoplasma was found to be similar to the albumen of milk, eggs, and blood [1] as far as coagulation was concerned. The albumen-like substance was conjectured to be the chief component of protoplasms and its existence was life. This "living" substance was referred to as protein, which means the primary or the initial, to emphasize the fact that it was not a "plain" egg-white. The discussion of these discoveries by Engels is widely known.

Proteins were firmly established in the scientific paradigm of the 20th century. However, a semantic misunderstanding occurred. The different terms in Russian and German became synonims and in English only "protein" remained. Early in this century proteins were found to be polypeptides, i.e., polycondensates of amino acids. Consequently, peptides were believed to be "responsible" for life and all life manifestations

to be the consequences of specific properties of polypeptides.

Today proteins are viewed as major components of protoplasma but they are not the proteins in the original sense. Protoplasma includes also other biochemical components such as nucleic acids, lipides, and polysaccharides without which life is impossible. Much effort was needed to prove that proteins were irreducible to albimen-like substances and that the term "living proteins" was a misnomer. The story of determining the bioinformational function of nucleic acids is especially dramatic.

After nucleic acids were discovered by F. Miescher in 1868-71, they were studied chiefly by chemists. The biological significance of nuclei acids was underestimated; in particular, they were regarded as supporting structures in the chromatine of the chromosomes. On the other hand, E. Fischer and others found that the combinatorial diversity of amino acid sequences in the polypeptide chain was practically unlimited. This was in good agreement with the "proteinic" function of albumen-like substances. Consequently, the mechanism of hereditary reproduction of traits was reduced to molecular mechanisms of reproducing, or copying, the unique sequences of amino acids in polypeptide chains.

A. A. Kolli was the first to realize this in 1893. N. K. Koltsov tried to unravel this mechanism in general form in 1927 [2]. He did not think that a sequence of monomers such as amino acids could be reproduced in a polymer chain by a purely kinetic mechanism such as attachment of a specific amino acid to the growing polypeptide chain which would have to proceed much faster than attachment of other amino acids. Kinetic mechanisms alone would result in frequent errors. Koltsov proposed that a sequence of monomers could be reproduced in polymer chains via matrix replication. In this theory the growth of a polymer chain is similar to

crystallization. Free monomer molecules specifically adsorb on the existing "parent" polymer chains, and then intermonomer bonds form.

Koltsov's discovery was a great impetus to further development of biology. The structure and replication of deoxyribonucleic acid (DNA) molecules were decoded; protein was found to be synthesized through translation of genetic information during the synthesis of polypeptide chains in compliance with the nucleotide sequence in the molecule of the matrix ribonucleic acid. This principle helped explain the molecular nature of inheritance, variability, and reproduction. It was incorporated into the fundamentals of a new science, molecular biology. However, Koltsov himself failed to overcome the traditional view that protein, rather than nucleic acids, was the carrier of genetic information. It took about 15 years for the importance of nucleic acids to be recognized. Even when O. Avery and his co-workers found in 1942 that the pneumococci transforming factor in Griffits' experiments of 1927 was DNA, this finding was held in doubt because it was in conflict with the belief that protein was the core of life.

The misinterpretation of the terms "protein" and albumen also held back the evaluation of the significance of lipoprotein membranes, still another major component of the cell. The "living protein" concept seemed incompatible with the role that the interface played in life processes. Consequently, scientists found it difficult to view biological membranes as structures that produced the nonuniform distributions of the ions in the cell-environment system, cell excitation, and generation of nervous impulses until A. Hodgkin and E. Hucksley's experiments [3] with giant axons of squids demonstrated beyond any doubt that the ion gradient and excitation propagation in the nerve were indeed dictated by the functions of nervous membranes. The temporary

"triumph" of the sorption theory served only to retard research in the biochemistry and physics of biological membranes.

On the Kinetics of Oscillatory Chemical and Biological Reactions

Oscillatory processes are extremely important in the life of various organisms. Thus, they set the pace of the "biological clock", many kinds of movement (flight muscles in insects, the heart beat, and bowels movement), and interaction of species in biocenoses. In chemistry oscillatory operating modes provide an insight into the kinetic mechanisms of numerous reactions. Oscillatory processes in "active biological and chemical environments" result in autowaves [4].

The history of research in self-sustained processes also illustrates the delays in acceptance of new scientific truths.

The theoretical possibility of self-sustained processes in chemical and biological homogeneous reactions was proved in 1910 by A. Lotka who described the interaction between two kinds of organisms or molecules with damped oscillations of the interaction and reactant concentration rates. Periodic oscillations in heterogeneous physico-chemical systems had been discovered in late 19th century by R. Liesegang. The insoluble salt periodically precipitated when one of the reactants diffused in a two-dimensional space filled with another reactant (Liesegang ring). These phenomena were later observed in various physico-chemical systems. In particular, these phenomena account for the concentric patterns in some minerals such as agate, malachite, and jasper. In single-phase, or homogeneous, solutions, however, oscillatory modes could not be experimentally observed for a long time. True, in 1914-17 attempts were made to detect them in enzy-

matic reactions; later P. P. Lazarev pointed to a possible important role of biochemical oscillatory reactions in physiological processes; no research of this kind was, however, carried out at that time.

A consensus gradually formed that oscillations of the reaction rate (of concentration, or of the states of the reactants) in homogeneous systems were in conflict with the statistical physics. Indeed, with the immense number, 10^{12}-10^{20}, of reacting molecules the probability that all or a noticeable part of them are in one state out of a number of possible states at the same time is practically zero. The only weak point in this reasoning was application of equilibrium thermodynamics to an obviously non-equilibrium system. Nevertheless, the impossibility of periodic modes in homogeneous system became "increasingly evident". In 1941 D. A. Frank-Kamenetsky who published profound results on periodic modes of chemical reactions [5] observed such modes in carbon oxidization processes ("cold flames") but he was not sure that the observed oscillations were feasible in a system which was certain to be homogeneous. "Cold flame" experiments involved heat transfer and convective fluxes of substances caused by interaction with the reactor walls. Nevertheless, Frank-Kamenetsky noted the possibility of oscillatory conditions in completely homogeneous systems.

In 1951 B. P. Belousov discovered a homogeneous periodic reaction in which citric acid was oxidized by bromate, with cerium ions as catalyst in a sulphuric acid medium. In this very illustrative and easily reproducible reaction the color of the reaction mixture alternated between yellow and colorless or (when an iron-phenantrolene complex was added) between red and blue.

However, two versions of his article were rejected by two journals because such oscillatory modes "were theoretically impossible". It was not until 1959 that an abstract of his

paper was published. After that his findings triggered extensive theoretical and experimental research. In 1980 B. P. Belousov, A. M. Zhabotinsky, A. N. Zaikin, V. I. Krinsky, and G. R. Ivanitsky were awarded a Lenin prize for the discovery of a new class of self-sustained wave (and oscillatory) processes.

The strength of bias and consensus is such that the experimenters notice only those results which fit their views. B. Chance, the well-known biochemist-biophysicist, showed in Moscow University in 1963 a slide of the curve of a phosphofructosokinase reaction where the periodicity was obvious. In response to my question Chance said that he did not see any periodicity and that only instability of the recording system was obvious. A discussion followed and he agreed that oscillatory modes were "quite legitimate" in homogeneous biochemical reactions.

Even in this "innocuous" case the research was held back for 10 to 15 years.

Reproducibility of Experimental Results and "Paradoxical" Observations

The progress of science is retarded to a significant degree by the impact of prevailing views on the processing and interpretation of the experimental data.

In this century the probabilistic picture of the world has taken root in the minds of scientists. Early in the century the methods of statistical treatment of measurement results were developed, a statistical theory of mass processes was worked out, applications of the probability theory proved quite successful, the experiment design theory and a host of probabilistic theories and concepts sprang into existence, including Shannon's information theory and approaches to

the notions of the meaning and value of "information units". This "probabilistic view of the world", however, proved to be a mixed blessing.

Indeed, in compliance with the stochastic approach only reports on reproducible phenomena are regarded as credible. Very rare events and phenomena occur, however, which the observer (unlike the experimenter) cannot influence. The reports on such events can prove erroneous. But they can also be truthful. Some phenomena cannot be reproduced just because their characteristic time does not coincide with the experimenter's life span. Therefore it is the duty of scientists to take note and carefully record such rare "irreproducible" events for posterity regardless of their "strangeness" or "paradoxicalness".

In the probabilistic approach it is a standard practice to "reject", i.e., to neglect and even not to record the measurement results which differ from the average, or mean, values by more than 3σ, where σ is the standard deviation from the mean. Consequently, in numerous experiments the data which may be quite valuable are neglected. In graphical representation of the results the curves leave out points representing large deviations.

The same attitude is obvious in smoothing the results, which is, in fact, an illegitimate approximation of the results by smooth monotone functions. In effect, the most important specifics of the process are frequently disregarded. Indeed, thorough analysis of the "scatter" of measurements is now a burning necessity. Still, irregular deviations from the mean are, as a rule, classified as experimental errors. The error of the method is thereby increased. The fluctuations of measured values with root-mean-square amplitude over three to four per cent may be caused by physical factors of extraterrestrial origin or by the internal state of the object. Such is the case of the characteristic discrete distribution of

the measurement results and the characteristic spectrum of the actual fluctuations [6].

In determining such a spectrum the tenets of stochastic determinism have to be overcome; indeed, the regular (reproducible!) shape of such a fluctuation spectrum is not observed unless the number of measurements is not very large. When this number is high, the modulation by low frequency fluctuations causes the spectrum discreteness to deteriorate and the spectrum becomes increasingly similar to smooth Gaussian and Poisson distributions.

Stochastic determinism makes it psychologically difficult to see the truth of reports that a system (chemical, physical, or biological) responds to factors (stimuli) whose energy is below the average thermal energy kT. Such reports are rejected as a priori false because these perturbations are supposed to dissipate within a very short time.

This widely spread belief is, however, a fallacy because the frequency response of the perturbation is neglected. The perturbation energy has to be compared with the amplitude, or the probability density, of this frequency in the Boltzmann distribution rather than with kT. As a rule, the experiments are concerned with the action of superequilibrium intensities of sound or radio waves. It is therefore required only to ascertain whether selective (resonance) energy absorption occurs at this frequency. Resonance absorption, especially in the low frequency range has for a long time been regarded unreal for biochemical (biophysical) systems. Recently, however, conditions for high-Q resonance at tens or hundreds of Hertz have been found quite feasible in numerous biochemical processes [7]. A. P. Sarvazyan discovered the possibility of resonance absorption and of the effect of low-frequency sounds in biological objects [8].

Similar psychological barriers had to be overcome in studies of the effect of weak low-frequency magnetic fields on

chemical and biological systems. Recent papers have demonstrated that there are no theoretical points of principle which would make such effects impossible. What is needed now is reliable, in this case reproducible, experimental data.

Consequently, the kT criterion is in many cases used fallaciously because the researchers blindly follow the traditions of the probabilistic approach. Recently the guidelines of the stochastic determinism according to which the stochastic behavior of observed phenomena is dictated by the summation of a set of independent, "disordered" even have been radically revised.

The probabilistic approach has undoubtedly been helpful in medicine. Indeed, mean statistical characteristics give an insight into the origin and spread of diseases, the effect of drugs, etc. They cannot, however, describe an individual patient. What is more, the smoothing, approximation by monotone functions, neglect of possible discreteness (inhomogeneity of the sample, and rejection of extreme points) tend to produce results utterly inapplicable to specific cases.

References

1. Шамин А. Н. Химический синтез белка. М.: Наука, 1969.
2. Кольцов Н. К. Организация клетки. М.; Л.: Биомедгиз, 1936.
3. Hodgkin A. L. The Conduction of the Nervous Impulse. Liverpool University Press, 1964.
4. Жаботинский А. М. Концентрационные автоколебания. М.: Наука, 1974 (see also "Autowaves: an interdisciplinary finding" by G. R. Ivanitsky, V. I. Krinsky, and O. A. Mornev, in this collection.
5. Франк-Каменецкий Д. А. Кинетика сложных реакций.— *Успехи химии*, 1941, т. 10.
6. Шноль С. Э., Коломбет В. А., Иванова Н. П., Брицина Т. Я. Макроскопические флуктуации — общее свойство водных растворов различных белков и других веществ, статистический, спектральный анализ макроскопических флуктуаций.— *Биофизика*, 1980, т. 25.

7. Назаренко В. Г., Сельков Е. Е. Автоколебания в открытой биохимической реакции с субстратным угнетением.— *Биофизика*, 1981, т. 26.
8. Сарвазян А. П. Специфические механизмы биологического действия импульсного ультразвука, связанные с динамикой биологической систем.— В кн.: Молекулярная и клеточная биофизика. М.: Наука, 1976.

On New Knowledge in Biological Studies

B. V. BIRYUKOV

The birth of new scientific information is a laborious, dialectic process. Darwin's theory of evolution, one of the most important scientific discoveries of all times, also brought about unscientific "scum" such as blind application of biological laws to human society and to the internal world of a human personality. Cybernetics aroused a lot of interest because of its biological and psychological applications. Some proselytes of this science of control and data processing in complex systems spoke of the advent of "thinking machines" and contributed to the making of an atmosphere of sensation around cybernetics. The progress of genetics, neurophysiology, and neuropsychology was equally difficult. The opinions and views in these fields were so conflicting and some of the phenomena so unexpected that many biocybernetic, neurological and psychophysical results made sensations.

What is then sensation in science and what are its basic features?

A sensation in science is a report of a real or apparent scientific or technological achievement which seems to be

very important and entirely new for the general public as well as for the scientific community. A sensation holds a promise of solving a great "mystery" in cognition, of a breakthrough towards the unknown, of a departure from the established knowledge. But as everybody would agree, the word "sensation" has negative overtones in the estimation of a scientific event. Why is it so?

Before answering this question, one should note an inevitable feature of all sensations, be they scientific or not. A sensation has to do with man, his environment, life, interests, needs, and expectations. The sociologists find that the potential consumers of goods or services respond to advertisements when these somehow strike a sensitive cord in the human soul. A scientific, technological, or industrial innovation may remain known only to a narrow world of specialists unless people at large become aware of its importance.

More than a century ago N. I. Kibalchich, a Russian engineer and revolutionary, put forward an idea of a jet engine; somewhat later Tsiolkovsky wrote of space exploration by using jet propulsion. The reports did not create a sensation. At that time aviation came to the fore. Flights across the English channel, across the Atlantic Ocean, and to the North pole were what made sensations; the outer space seemed too remote to be interesting. The situation changed radically when the first satellite was launched, when Yuri Gagarin flew in space, and when, in fulfilment of Jules Verne and G. H. Well's prophecies astronauts landed on the Moon. To date significant achievements of the space science and technology are quite capable of making a sensation.

Today philosophers, fiction writers, aestheticians, and engineers as well as mathematicians and logicians discuss the famous Gödel's theorems on the limitations of logico-mathematical formalization. But did many mathematicians

knew of these theorems in 1930s or '40s? Just a few dozens even heard of them because the significance of this discovery for human cognition, not excluding mathematics, and for "the human world" was uncertain. Mathematicians have proved another theorem, so what? The situation changed dramatically when cybernetics and computers arrived on the scene. Gödel's theorems were found to have a direct bearing on logical and computer modeling of intellectual processes, and hence, on the automation of many widespread kinds of mental activities. Clerks, engineers, designers, etc. expected an imminent invasion of intelligence "amplifiers" into their life. Non-mathematical statements of Gödel's theorems became very popular.

As far as the expansion of human knowledge and skills is concerned, there are three kinds of sensation, namely, unscientific, pre-scientific, and scientific. The negative implication of the term "sensation" ("scientific sensation") is attributable to the fact that sensations may prove unscientific, created by what is referred to as "pseudoscience".

When is a sensational report, even coached in a scientific language, unscientific? It is when it is in conflict with established important facts and laws. Some readers will remember the stir in popular press around the so-called Dean engine which boiled down to perpetual motion. Much noise was made by the "discovery" of Professor O. B. Lepeshinskaya who detected birth of living matter from lifeless matter, or, in scientific terms, formation of living cells from non-cellular components. The reports were sensational because of their promise. Indeed, it would be nice to have an engine which does not consume energy or to see the genesis of life. These "breakthroughs" proved to be illusory, and specialists knew it all along, because they were incompatible with the scientifically proved physical and biological laws of nature.

Pre-scientific sensations are different. This term naturally

sticks to reports of data collected by scientifically sound methods and agreeing with the laws of nature but being at the crossroads of knowledge in that they may be refuted by subsequent theoretical and experimental research. Scientific search which is widely reported as pre-scientific sensation is useful no matter whether it is successful or not.

This case is illustrated by the so-called astrobiology which was vigorously explored in the "pre-space" 20th century by G. A. Tikhov, a Corresponding Member of the USSR Academy of Sciences. The sensational reports of research on life manifestations on other planets, in particular Mars, were rejected first by "earth" and later by "space-based" science. Still, the methods worked out by that team were in a sense predecessors of today's space biology.

Finally, a sensation is scientific if the reported results fit the existing picture of the world, albeit after its transformation in the light of the results. All significant achievements of cognition which have a direct impact on human life in time become sensational without negative implications. This was the case of the theory of relativity, the discovery of atomic energy and ways to release and utilize it, and indeed of all important stages in space exploration.

The boundaries between the three kinds of sensation are, of course, relative. The opinions of scientists may differ and quite legitimate results may be occasionally classified as "pseudoscience". This happened to mathematical intuitionism which was dismissed as a "curiosity" by a group of French mathematicians known under the pen-name of Nicolas Bourbaki.

In a popular book by a physicist in this country the paradox of a village barber who is told to shave whoever does not shave himself (and so the question is, should he shave himself) was dismissed as "rubbish". What the author did not know was that a similar paradox rewarded in logico-

mathematical terms was used by Gödel in proving his now famous theorems. The proposed "elimination" of this paradox by stating that such a barber could not exist is merely a repetition of a well-known way to solve logical antinomies.

The pre-scientific cannot on many occasions be separated from the scientific until after much time elapses after the first sensational reports. Signals coming from the outer space were for some time believed to be messages from extraterrestrial civilizations but later found to have natural origins. But who can say for sure that some of such signals will never turn out to be artifacts of extraterrestrial civilization? Scientific news makes a sensation either when an old problem is restated in a challenging way or when an outstanding problem is resolved. The latter is the case of some hypnosis phenomena, autogenic training, and physical fields generated by a living organism [1].

Indeed, it would be naive to think that all "mysteries" of life have been resolved by science. Neither scientists nor laymen think so. This is why real but unexplained phenomena arouse so much interest among general public.

Because the relevant processes are difficult to understand the methodological aspects of evaluating the reports on research in the bioinformation and bioenergy fields have to be discussed in some detail.

The sensations in these fields are prescientific or scientific ones, foreshadowing possible significant discoveries.

First of all, the "foundation" of the "building" of reality, especially the living nature, has the property of reflection. Various physical fields of which science does not yet know much are generated by the activities of the living matter in response to exogenous signals. For instance, a better understanding of the homing of birds and other animals would expand our knowledge of the property of reflection as an attribute of nature in its entirety. Some forms of reflection may

be unknown to science. The quantum physics may yet contribute to detecting and exploring these forms.

A major factor to be reckoned with is the active functioning of consciousness, mind, and generally the living matter. Emphasized in Karl Marx's "Theses on Feuerbach", this principle was reformulated in Lenin's "Philosophical notebooks": "Not only does man's consciousness reflect the objective world, but it also creates it." The principle of active functioning of the living matter sheds light on numerous phenomena such as relation with the characteristics and states of persons involved in relevant experiments; for the very atmosphere of the cognitive process, insofar as it is created by people as personalities, as doers, cannot fail to get reflected on the structures of those physical fields that emanate from the living matter.

Cognition is retrieval of data from the environment. But in reflecting the world man also brings data into it in the course of his productive and cultural activities. But, is more "intimate", and so less noticeable, introduction of new information into the environment possible? In the light of the latest data on the variety of physical fields of the living matter and their dependence on the physical state of the human participant a positive answer may be possible.

If it proves feasible, the concept of the "controlling" function of the conscience will have to be revised, in particular, as far as the theory of the second signal system and the semiotic views of sign systems as tools governing the human behavior are concerned. Indeed, in both cases the word, this "signal of signals", is assumed to perform a data processing and control function owing to a certain meaning it triggers rather than to its material form, such as sound oscillations, or to the representation of sound in some material medium.

The word acts, in effect, as a tool for displaying the mental states which are brought about by neurodynamic processes. In autogenic training and hypnosis the speech and thinking act as controllers of some aspects of physiological processes. Some psychologists believe that any biological function can be influenced by a meaningful word.

Let us also recall Lenin's thesis of the relativity of the difference between the material and the ideal outside the scope of the basic philosophical question. The attempts to model the generation of various physical fields such as electrostatic, magnetic, thermal, etc. which interact in mental activity may prove to be outside this scope. These, at the moment rather weak, attempts rely on the tools of the quantum mechanics which is regarded as a reflection of both the physical reality and the consciousness which interacts with this reality.

Since the cognitive picture of the world cannot ever be complete its exploration will continue as long as science is alive. Hence, new findings in complex data processing phenomena in living systems should by no means be overlooked.

A question is often asked, should not a "new physics" be deleloped to interprete these phenomena. The researchers have not come to a consensus but most of them believe that there is no need in postulating it; this viewpoint is reflected in the articles of this collection. The interaction of the physical and mental phenomena (at least in the domain now explored by science) can be successfully tackled by today's experimental physics in conjunction with cybernetics, informatics, neurophysiology, and psychology. The tools of the information theory may prove helpful in evaluating the throughput of the channels created by the interacting physical fields of the living matter; neurophysiology and psychology may provide an insight into the dependence of the

data-processing activities on the functioning of the right hemisphere. At least some of the information generated by living systems is known to be pictorial and fragmentary rather than logical and so does not readily yield to studying.

On the other hand, further progress of physics, in particular, discoveries of yet unknown forms of energy or information and an extension of physical laws (which would incorporate the familiar laws as particular cases) may provide new cognition tools.

Another methodological aspect is the simple versus complex relation. Some data processing phenomena in the living nature may prove to be beyond the "complexity threshold" in the sense of John von Neumann [2]. Many researchers believe that "large" subtly functioning systems can, thanks to the interaction of their subsystems, possess an immanent consciousness or its analogs as an inherent functioning tool to reflect the reality and to exercise antientropic influence on the environment and themselves. This fascinating assumption, which is akin to that of the existence of intelligence in the outer space, can be neither confirmed nor refuted today.

References

1. See the articles "Man's magnetic fields" by V. L. Vvedensky and V. I. Ozhogin and "The physical fields of biological objects" by Yu. V. Gulyaev and E. E. Godik in this collection.
2. See also: Берг А. И., Бирюков Б. В. Познание сложных систем и проблема нетранзитивности научного объяснения.— В кн.: Философско-методологические основания системных исследований. Системный анализ и системное моделирование. М.: Наука, 1983.

Criteria of Existence and Conflicting Situations in Science

D. I. DUBROVSKY

Reference to authorities has proved to be a poor way to close down or solve scientific problems; in particular, this is true of data processing in living systems. It is a typical situation. Some scientists demand the unconditioned "winding up" of a particular project, not bothering about a discussion, while others insist on going ahead with it.

Voting is not a good way, either, to arrive at the truth. What is needed is a philosophical methodological analysis so as to understand by what criteria a phenomenon is believed to exist or not to exist.

Whoever says that a phenomenon does or does not exist is guided by some criteria of existence which are often used intuitively, without giving a thought to their justification. Significant theoretical difficulties in determining these criteria should, at least, be recognized by those who want to approach the problem in a truly scientific way.

Numerous phenomena are acknowledged by practically everybody but have not been explained in scientific terms. Nobody would deny that in many cases one's mood and feelings about ourselves can be understood from the expression of one's eyes. But no scientific explanation of what changes "the expression of one's eyes" is available. Another example of the same phenomenon is the ability of the yogi to control their vegetative functions. The miraculous abilities of people who competed with an electronic computer in the calculation rate, or of Shereshevsky with his eidetic memory (described in "A little book on large memory" by the well-known

psychologist A. R. Luriya) or of the geniuses of science and art are no less understandable.

These surprising facts remain unexplained but have never been in doubt, probably not so much because they are on record but because they do not contradict the scientific fundamentals.

Let us discuss briefly the criteria which are explicitly or implicitly used in admitting or denying the existence of putative phenomena.

In natural sciences such criteria are the laws of physics but they can also be philosophical fundamentals which follow from the historic experience of cognition and common sense.

In many cases several criteria have to be concurrently employed. In some cases the relative values of criteria are different and this may hinder the decision making. Thus common sense may be in conflict with the latest scientific theories. In particular, common sense cannot, at least today, comprehend singularity, the key notion of today's cosmology.

Similar conflicts, albeit not so acute, may arise between scientific and philosophical principles, the latter being much more permissive. The science of the 19th century knew nothing of electrons or quasars, the principles of the classical physics did not allow for the existence of virtual particles or "black holes" but the inexhaustibility of the matter, the historism and dialectics of the course of cognition admitted the existence of yet unknown material structures and interactions. Philosophy is aware that the existing knowledge is limited and thus stimulates its expansion. The laws and principles of specific sciences such as physics, chemistry, biology, etc., while acting as existence criteria, cannot by themselves dictate the final judgement, especially as far as inexistence is concerned. A physicist who says that his science cannot admit the existence of a phenomenon is not nece-

ssarily right, either logically or methodologically. A scientific and physico-mathematical screening is certainly useful and necessary but the category net of this filter is historically limited. In addition, two more factors should be recognized.

First, the criteria may be interpreted in different ways, as are descriptions of the phenomena themselves. One such criterion may be the gravitation law which applies to every physical object on the earth and in its environs. But this does not imply that any unknown object suspended in mid-air is a mirage. In the same way the inconsistence of the observed phenomena with a fundamental physical law may be refuted.

Second, a set of criteria or postulates, chiefly philosophical and scientific have to be adopted, rather than a single one. What is important, this set is bound to be incomplete because of the historically limited knowledge, and in agreement with the principles of materialistic dialectics which leaves room for creative innovations in nature, human culture, and individual consciousness.

In this light, at least in numerous cases, the decisions on the existence or otherwise of phenomena recorded (or assumed) by someone else are merely probabilistic. Then, because cognition is historically limited, it would be more reasonable to admit some probability of their existence*.

In general, there are three possible kinds of answers to the question, whether a phenomenon exists.

1. The answer is unambiguous. My desk exists, the electron exists, the centaurus does not.

* Some topics, such as the relation of empirical and theoretical knowledge, or of the subjective and inter-subjective, the observed and introspective, the sensual and rational, the phenomenon of faith, and methodological aspects in studies of mental phenomena are very important for the analysis of the existence problem; however, they go beyond the scope of this article.

2. There is a certain probability that the phenomenon does or does not exist. Thus, it is very probable that there are biochemical factors capable of curbing and then eliminating malignant tumors; it is probable that there are yet unknown ways to encode and transmit data; the putative snowman most probably does not exist.

3. Finally, in some cases no unambiguous answer is possible because the alternatives are equiprobable. Such is the question, can reasonable beings capable of withstanding a radiation dose of 10,000 R and a temperature of 10,000°C exist in the universe? Such questions are not necessarily pointless for they may help to expand our knowledge.

Every thinking human being, and the entire mankind, find themselves simultaneously in three cognitive situations: (1) We know that we know, for instance, that everyone has a heart or that $E = mc^2$; (2) We know that we do not know, for instance, we know that malignant hyperthermia must be caused by some factors but we do not know what they are; (3) We do not know that we do not know. Thus, ancient Greeks knew nothing of viruses or nuclear reactions and were unaware of this ignorance. Recognition of this possibility is extremely important in the analysis of existence criteria.

Consequently, both in the environment and in our mind there is something we are unaware of which can manifest itself as weak symptoms, be observed, statistically processed and amplified so that the situation may change from the third to the second case. In empirical studies, or those scientific fields such as psychology where the theoretical knowledge is not unambiguously systematized, a phenomenon may be discovered which cannot be explained in terms of familiar phenomena and needs clear-cut description and understanding in terms of the principles and fundamentals of the field.

In human psychology and interpersonal communication

numerous various phenomena cannot be convincingly explained and so fall into the second and third cases.

In some cases of interpersonal communication we do not know what we do not know because the information carrier is uncertain. We do not know the physical equivalent of the "expression of the eyes". The inability to identify the physical process which acts as the information carrier cannot justify a denial of the fact of data transmission.

It is important to specify at this point, in what sense we do not know the data carrier. Every medium is the code; a description of the carrier is essentially a description of the code. The comprehension of the message implies that the code has been understood, consciously or otherwise. The latter is very important in communication. The "expression of the eyes", the meaning of the tone, and the grimaces are comprehended instantaneously. The essence of words in the mother language is understood, as it were, directly, without analyzing the sounds and phonemes. Consequently, knowledge of the information carrier implies conscious reflection of certain coding and of specific physical, chemical, spatial, and other properties of the information carrier in a specific self-organizing system.

In effect, different things may be unknown. These may be either the entire class of physical phenomena, their combinations, interconnections, and ranking which act as the carrier (code) for the specific self-organizing system or it may be some objectively existing but yet unknown physical phenomena that exercise control.

True, the list of discovered physical laws is obviously incomplete and a "conflict" is possible, as was the case of numerous optical phenomena that once "were in conflict" with the laws of the classical mechanics. (Overcoming these "conflicts" is the most challenging creative aspect in physical cognition.)

At this point we come to grips with the old and tormenting question of the ratio of the mental and the physical. The age-old vulgar-materialistic answer is that the psychological phenomena are merely a variety of bodily physical processes (recall the ill-famed "The brain emanates a thought as the liver secretes bile"). This answer is refuted by the Marxist philosophy and leads specific researches into a dead-end by ignoring the specifics, in terms of contents and values, of mental phenomena.

The psychophysical and psychophysiological problems relevant in this context have been thoroughly analyzed elsewhere [1-3]. In this article one important fact must be noted. The mental is a variety of data processing rather than of physical phenomena. The qualitative difference between them is in the invariance of the information with respect to the physical properties of its carrier in the sense that although information does not exist outside or without its material carrier and the latter possesses certain physical properties, the same information can be embodied in, and transmitted by, physically different media, or be encoded in most different ways. To put it differently, information per se (in terms of its contents or value) is independent of the energy and other physical properties of the medium. (Thus, the message 'This is an oak tree' can be transmitted in different languages, by different graphical, acoustic, and other signals. The mass and energy of these signals may vary but the information remains the same.) Consequently, the laws of data transmission in themselves cannot account for all the aspects of data transmission.

The physical existence criteria cannot obviously be extended to all other fields of knowledge (or of the reality), notably psychology and social phenomena. Thus in physics and in natural history the chief requirement to an experiment is repeatability. This principle is not, however, the

necessary existence criterion in the humanities. In history the repeatability acquires a different significance. Julius Caesar lived just once. What I experienced tonight will not necessarily happen again. What I can do now I will not be able to do in twenty minutes from now but will probably be able to do tomorrow. For this reason the requirement of repeatability of an experiment or of observation is not universal or all-important.

A thorough Marxist methodological analysis of situations where we are and where we are not aware of our ignorance is a major factor in creative development of science.

References

1. Дубровский Д. И. Психические явления и мозг. М.: Наука, 1971.
2. Дубровский Д. И. Информация, сознание, мозг. М.: Высшая школа, 1980.
3. Дубровский Д. И. Проблема идеального. М.: Мысль, 1983.

New Horizons in Cognition

The Physical Fields of Biological Objects

YU. V. GULYAEV and E. E. GODIK

Physical fields are generated by any living being. Their distribution in space and variations with time contain important biological information which could be used, in particular, in medical diagnostics. What are these fields?

As a physical body, any biological object must be a source of equilibrium electromagnetic radiation. For a body whose temperature is around 300 K this thermal radiation peaks in the infrared range. For instance, man emits over 10 mW from every square centimeter of his body, or a total of over 100 W. This radiation propagates far since it falls into the transparence "window" of the atmospheric 8-14 μm range.

Our subject will be the possible transmission of data reflecting the functioning of the internal organs rather than the electromagnetic radiation from biological objects per se. In particular, the infra-red radiation is modulated by the physical processes which dictate the distribution and dynamics of the surface temperature.

Another channel (another wavelength band) is the microwave thermal radiation which contains data on the temperature and rhythms of human internal organs. In the decimeter wavelength range signals from a depth of five to ten centimeters are detected. At shorter wavelengths this depth decreases but the spatial resolution improves.

Fairly complicated digital processing of thermal radiation images obtained at different wavelengths provides a three-dimensional distribution of the temperature deep inside a living creature.

Electric fields of frequencies below 1 Hz are generated, as a rule, by electrochemical (above all, transmembrane) potentials which reflect the functioning of various organs and systems such as the heart, the stomach, etc. Unfortunately, the highly conducting tissues effectively shield the internal sources of low-frequency fields. This effect hinders solution of inverse problems, namely, determining the sources of such fields from measurement of the electric potential close to the body surface.

At the same frequencies the magnetic fields should be observed that are generated by currents, accompanying the physiological processes, in the conducting tissues. Unlike electrical fields, magnetic fields are not shielded by the living tissues. Consequently, the sources of magnetic fields can be localized more accurately. This is especially helpful in studies of the brain activities. This promising technique of medical diagnostics is now widely used throughout the world.

At higher frequencies, namely, in the optical, near infrared, and near ultraviolet ranges bioluminescence signals attributable to biochemical reactions inside the organism may be expected. This weak luminescence facilitates the monitoring of biochemical processes.

The human organism is transparent to acoustic waves of frequencies up to several MHz. Therefore it would be very enlightening to study the acoustic signals coming from deep inside the organism. In these studies the organism is monitored in the infrasound range and important data are obtained on the mechanical functioning of the internal organs, muscles, etc. The high frequency acoustic signals, including

noise, can be produced by various sources on the cellular and molecular levels. Localization of such sources with high spatial resolution would be an important breakthrough because the wavelength of acoustic signals is much shorter than that of electromagnetic radiation of the same frequency.

Equally important are measurements of the composition and the physico-chemical characteristics of the environment. The living being disturbs the environment by changing its gaseous and aerosol composition, ion concentration, conductivity, dielectric constant, and refractive index.

Methodologically, the studies of physical fields around living beings are very similar to passive remote sensing of earth, the atmosphere, etc. These methods have become very sophisticated and provide very significant data on the structure and functioning of their objects.

Biological objects are, however, substantially different from conventional physical objects. The state of living beings is essentially nonstationary. Therefore the picture of their physical fields cannot be studied without reference to the fast varying psychophysiological state of the organism; consequently, the physiologists have to monitor various physiological as well as physical parameters. Besides, any living being is a dynamic self-regulating system and so the picture of its physical fields should represent the characteristics of homeostatic control systems which could not be studied without close cooperation with physiologists.

Because of these differences the hardware has to meet certain requirements. The nonstationarity calls for simultaneous recording of the signals through several channels by using electrophysiological monitoring. Matrix or scanning antennas have to be used in every channel if the spatial structure of the field is to be obtained. The hardware must be fast enough to record the signals reflecting the changing sta-

te of the object. Practically every channel must be carefully screened from noise.

We did not try to develop essentially new hardware; instead we employed the state-of-art remote-sensing technology in studies of living beings. The primary objective was to develop the procedure of such studies. As a rule, the hardware has to be modified and some elements have to be developed anew by incorporating the new elements of semiconducting, superconducting, photoemission, etc. sensors of physical fields.

The hardware for studies of electric fields generated by living beings is now available. In an electrically screened room (Faraday cage) the ECG is remotely recorded from the subject's hand kept at a distance of 10 cm from the antenna which acts as a potential probe.

The so-called ballistograms are recorded from a distance of up to 2 m. The action of internal organs such as the lungs and the heart makes the thorax vibrate in a certain mechanical rhythm. As a result, the static charge always present on the body surface generates appreciable electric signals in the potential probe.

Our hardware remotely records much weaker signals such as the muscle microtremor (myogram), and the surface charge field variations due to the variations of the electrical parameters of the skin. In cooperation with medical researchers we study the possibility of using these signals for remote medical diagnostics.

A thermographic imager and an image microprocessor are integrated in hardware which monitors IR radiation in the 3-5 and 8-14 μm bands. This hardware yields thermograms with grades of 0.05 K.

In medicine thermograms are usually compared with reference patterns so as to diagnose pathology from deflections. Our approach was different. Because a living being

is, as noted above, a self-regulating system, the image obtained through any channel should contain data on the control systems. The temperature of a living being is a parameter which is regulated by homeostatic systems. Our objective was to detect the manifestations and to determine the characteristics of these systems in the 3D structure of the thermogram and its time variations. We expected that, following the heating or cooling of a body area, the temperature would return to the original value with an overshoot, characteristic of servo systems. The digital processing programs yielded temperature relaxation plots for any of the 128×128 points of the thermograms and detected areas of identical dynamics. The thermogram of a man was indeed found to include areas representing active control as well as those where the temperature relaxed monotonically.

Even at this early stage of research the points or areas which behave identically can be assigned certain functional parameters such as the characteristic time constant and the error signal. Changes in such descriptions reflect changes in the homeostatic control systems and will be useful in early medical diagnosis.

At present the variations of hand temperature with a period of about two minutes, and face temperature variations at the respiration rate are among the signals recorded in the IR range.

As for other ranges, highly sensitive instruments have been developed which register very weak bioluminescence in the visual range. The system includes a photon counter and a camera screened from external light. It records the luminescence of the oral cavity, the skin of the face, hands, etc.

The metabolism-induced environmental changes are also monitored by IR imagers (thermovisors). Using a filter which is transparent only in the waveband of the luminescence of carbon dioxide molecules the exhaled gas was visuali-

zed by its thermal radiation. With other filters, water vapor and other gases can be visualized. Furthermore, hardware has been developed for recording the variations in air conductivity around a living being.

Radiometric systems operating at wavelengths of 18, 10, and 3 cm have been tested with various types of contact antennas. Temperature variations of 0.1 K are detectable. These systems make it possible to monitor thermal radiation of human intestines, including the stomach. Thermographic imagers operating on other wavelengths are now under development in order to obtain thermographic profiles of tissues.

Experimental models have been developed for detecting acoustic signals at frequencies up to 100 kHz. Hardware for magnetic field measurements is being assembled.

Computers, special-purpose microprocessors, and a network of peripherals are integrated into an experiment design and data processing system which collects data, filters out the noise, restores the actual structure of the fields (or eliminates the distortions introduced by the sensors), analyses the dynamics in field generation and the inter-channel correlations (above all, it searches for correlation between physical channels and electrophysiological indicators). The most important and involved objective is, however, to study the feasibility of obtaining a 3D image of (thermal, magnetic, electrical, and acoustic) field sources.

At a later stage the sensitivity of living beings to biological and geophysical fields will be studied. But first the characteristics of fields have to be known which adequately represent biological objects. For physicists this is much more difficult than the study of physical fields because a living being acts as a very complex receiving system. This research cannot be carried out without close cooperation with biophysicists and psychophysiologists.

Research in physical fields around living beings is unthinkable unless physiologists, biophysicists, psychologists, and medical scientists join their efforts with instrument engineers.

Currently the Institute of Radio Engineering and Electronics of the USSR Academy of Sciences is engaged in joint research with a team of physiologists and psychophysiologists of the First Moscow Medical Institute and the Research Institute of Normal Physiology of the Academy of Medical Sciences. We also cooperate with the Institute of Higher Nervous Activity of the Academy of Sciences, Moscow University, Radiophysical Research Institute in Gorky, and numerous medical institutions.

The research is supervised by N. D. Devyatkov and Yu. B. Kobzaryov, full members of the Academy of Sciences.

Man's Magnetic Fields

V. L. VVEDENSKY and V. I. OZHOGIN

In late 1960s the progress of the physics of superconductors culminated in the development of a semiconducting quantum interference device, SQUID, an instrument whose operation is based on purely quantum phenomena such as the Josephson effect and interference of the wave functions of electron pairs in a superconducting ring containing a Josephson junction. A SQUID is the sensitive element of magnetometers which measure the magnetic field and, consequently, physical quantities such as electric current, magnetic susceptibility, displacement of magnetics, etc. The sensitivity of these instruments is at least 1,000 times better than that of

the best non-superconducting magnetometers. To maintain the superconducting state, which survives only at very low temperatures, the SQUID is placed in a Dewar flask with liquid helium. If the walls of the flask are metallic, the currents generated there distort the magnetic fields of sources outside the vessel. Special composite glass-plastic Dewar flasks have been recently developed where the SQUID or its input unit, made of superconducting wire (the so-called magnetic flux transformer), are within one centimeter from the outer wall and record undistorted magnetic field produced by outside sources at room temperature.

SQUID magnetometers were very soon employed in measurements of the magnetic fields generated by living organisms, above all, man. The analysis of these weak fields became a new line of research known as biomagnetism in contrast to magnetobiology which was concerned with the effect of strong magnetic fields on biological processes. Biomagnetic signals are very weak and their measurement is not a simple matter, chiefly because of the high level of magnetic noise in our environment (see Fig. 26).

The most radical way of eliminating the noise is to use a fairly large room where the noise is reduced by magnetic shielding. For the subtlest biomagnetic brain research the noise should be reduced to one millionth of its usual value, which is done by using multilayer walls of a magnetically soft ferromagnetic alloy such as Permalloy. A shielded room is costly and only the largest scientific centers can afford it. There are less than ten such rooms in the world.

Magnetic noise is mostly generated by chaotic oscillations (fluctuations) of the earth magnetic field and industrial electrical units. In locations far away from strong anomalies and electric machinery the magnetic field does fluctuate with time but is spatially homogeneous and does not change much over distances comparable with the dimensions of a

human body. The body-generated magnetic fields weaken fast with the distance from the organism. In effect, the external fields, albeit much stronger, have a lower gradient (i.e., the rate of change with the distance from the object) than biomagnetic fields do.

A SQUID receiver is made sensitive only to the gradient and is referred to as a gradiometer. When the external (noise) fields have noticeable gradients, the second spatial derivative of the magnetic field inductance has to be measured. Such an instrument is a second-order gradiometer which can be used in conventional laboratories. Still, "magnetically quiet" environment is preferable and some research teams work in nonmagnetic buildings in the countryside.

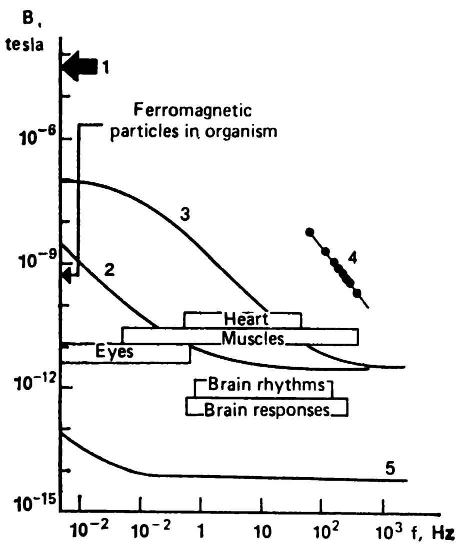


Fig. 26. Typical magnitude and frequency spectra of biomagnetic signals and noise in the environment

1—earth field; *2*, *3*—geomagnetic and urban noises, respectively; *4*—noise of the mains; *5*—SQUID sensitivity

Vigorous biomagnetic research is under way by using both techniques. There is a wide variety of biomagnetic phenomena and in different cases different degrees of noise suppression are admissible.

The Nature of Biomagnetic Fields

The magnetic fields of a living organism may be generated by three kinds of sources. First, these are ion currents resulting from the electrical activity of cellular membranes (chiefly of muscular and nervous cells). Another kind of source are minute ferromagnetic particles that found their way or were deliberately introduced into the organism. These two kinds generate their inherent fields. The superimposition of an external magnetic field reveals the differences in the magnetic susceptibility of different organs since they perturb the applied field.

In the latter two cases the magnetic field is not accompanied with an electric field; for this reason only magnetometric methods can be used in the studies of magnetic particles in the organism and of the magnetic properties of various organs. In fact, biocurrents also redistribute the electrical potentials on the body surface. Charts of these potentials have for a long time been used in research and medical practice (ECGs, EEGs, etc.). Their magnetic analogs, i.e., magnetocardiography and magnetoencephalography, which record signals from the same electrical processes in the organism, might be expected to provide practically the same data on the organs. But, as follows from the theory of electromagnetic phenomena, the shape of the source of current in a conducting medium (viz. the organism) and the inhomogeneity of this medium have different effects on the distribution of magnetic and electric fields. Some kinds of bio-

electric activity manifest themselves chiefly in the electric field and produce a weak magnetic field while for others the picture is reversed. Thus, there are many processes which would be better observed magnetographically.

Magnetography does not require a contact with the object; consequently, measurements can be taken, e.g., through a bandage. This is convenient and, which is more important, is an essential advantage over electrical methods because the spots where electrodes are placed on the skin may become sources of slowly changing contact potentials. Such parasitic noise does not occur in magnetographic methods. As a result, magnetography ensures reliable results in studies of slow processes (with characteristic time of several tens of minutes).

Magnetic fields fall off steeply with the distance from the source because they are generated by relatively strong currents in the operating organ itself whereas the surface potentials, by weaker and "widely spread" currents in the skin. For this reason magnetography provides more accurate localization of the bioelectrically active spot.

Finally, additional useful data can be obtained because the inductance of the magnetic field as a vector is characterized by the direction, as well as the magnitude.

Electro- and magnetographic methods do not compete. On the contrary, their combination provides the most complete information possible on the processes. In some cases the one and in some, the other method is preferable.

Magnetocardiography

The heart is the most powerful source of electric and magnetic fields in the organism; magnetocardiography had existed long before SQUID was developed. But it was not be-

fore SQUID magnetometers were widely applied that magnetocardiograms (MCGs) equalled electrocardiograms (ECGs) in clarity. They are very much alike but heart disturbances have different effects on electrical and magnetic measurements. In many laboratories of the world the data are now being accumulated for subsequent classification of changes in MCGs caused by heart troubles.

The advantages of magnetography are most obvious when slowly changing and, even more so, constant signals are to

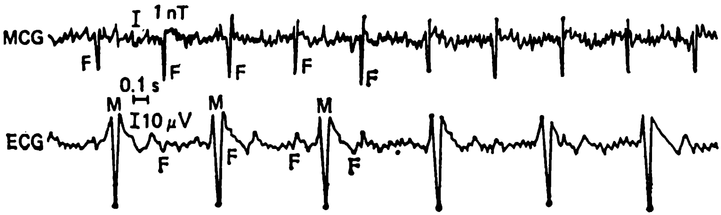


Fig. 27. Magneto- and electrocardiogram of fetus in the womb
F—fetus' heart signals; *M*—mother's heart signals

be recorded. It was magnetography that first detected continuous "alarm currents" signalling the clot of the coronary artery in dogs.

Another serious success scored by magnetocardiography is the observation of the fetus MCG (Fig. 27). The clear-cut localization of the magnetic field in the vicinity of the source makes it possible to distinguish the fetus signals from the stronger signals of the mother's heart whereas electrical signals are largely mixed up because of the spatial spreading of the surface ECG currents.

Magnetography also measures the characteristics of the blood flow in the heart. In a small external magnetic field the periodic ejection of blood generates an alternating mag-

netic signal which is indicative of the flowrate and velocity of the moving liquid.

A new line of research in magnetography, high resolution MCGs, is similar to neuromagnetic measurements which will be discussed below. This technique ensures a more "thorough" study of those intervals in the heart cycle during which the muscle is quiet and the researcher can measure weak magnetic signals which accompany the nervous impulses propagating in the heart. These signals were found to be invariable for about 20 cycles, then to change the shape slightly and maintain the new shape for the subsequent five to ten cycles, etc. This data may hold a clue to the understanding of nervous processes in the heart.

Ferromagnetic Particles in the Organism

The skin and the organism of most people, notably those engaged in metal processing industries, contain small ferromagnetic particles whose magnetic fields may handicap high-sensitivity biomagnetic measurements. These disturbances can be eliminated by demagnetizating the particles in the external ac field of decreasing amplitude. On the other hand, the fields of ferromagnetic particles can be enhanced by magnetization in a fairly large constant field. Then the measurements can be taken even by less sensitive instruments, especially when the concentration of ferromagnetic particles in the organism is high. Thus, conventional (ferroprobe) magnetometers are used in determining the amount of iron dust in the lungs of welders.

SQUID magnetometers detect minute amounts of paramagnetic (whose magnetization is significantly weaker) as well as ferromagnetic impurities. The high sensitivity of the method may be useful for many diagnostic purposes.

SQUID magnetometers detect the magnetic signals of iron microparticles which found their way into the stomach with food; in this way fresh and digested foodstuffs can be distinguished. Besides, measurements of the magnetic field distribution around the human torso following inhalation of innocuous Fe_3O_4 magnetite make it possible to observe the spots where dust settles preferably in the lungs, or to find the rate of its natural removal (which was found to be slower in smokers). In this way the stagnation spots (inflammations) can be detected and the results of physical factors (ultrasonic, irradiation, VHF heating, or a variable magnetic field) on the dust particles may give a clue to the nature of pathological changes in the spot. In fact, any organ penetrable by magnetic particles can be studied in this way. Thus, the oscillatory movements of the eyes (tremor and saccades) and of the middle ear are detected by fixing a tiny ferromagnetic particle in the desired spot and recording its movements which cause variations of the magnetic field.

The Magnetic Fields of Internal Organs, Skin Muscles and Eyes

Magnetic manifestations of the biological activities have been noticed in many organs of living organisms. Fields, either continuous or oscillating with a period of several minutes, are typical of the human stomach, the shape of the signal explicitly depending on the stomach state. This finding may be applied to diagnosis of stomach troubles.

Magnetic fields of dc currents were found to be generated in the skin when the hair is touched. Electrographic detection is made very difficult by parasitic potentials in the spots where the electrodes are fixed and by the pressure they exert on the skin.

The magnetic fields resulting from contraction of human skeletal muscles have also been measured. A record of these fields as a function of time is referred to as a magnetomyogram, MMG. In addition to the high frequency components (10-150 Hz), which are also recorded electromyographically, a slowly varying MMG component is found to be generate-by contraction or slight massaging of the muscle. Such magr netic field is characteristic of leg muscles; it may last foe about an hour. The currents which generate these fields ar-believed to play a major role in the regeneration of the extred mities, in particular, in curing broken bones.

The eye is known to be a source of a fairly strong electrical field because the action of the retina induces a potential of up to 0.01 V between its forward and rear parts. As a result, an electrical current flows in the surrounding tissues; its magnetic field can be monitored as a magnetooculogram (MOG), due to eye motion and as a magnetoretinorgam, MRG, due to variation of the retina illumination. It was also found that in the eye the magnetic field induction is significantly higher than that of the brain (see Fig. 26). Therefore the configuration and other characteristics of these fields should be known before starting magnetographic studies of the brain, in particular, of visual perception.

Neuromagnetic Fields

The functioning of the brain, which remains largely a mystery, produces both electric and magnetic fields. The strongest signals are generated by spontaneous rhythmical activity of the brain. Electroencephalography has been helpful in classifying these rhytms and associating them with the functional brain states such as wakefulness, various phases of the sleep and pathologies such as epileptic fits.

Electro- and magnetoencephalograms (EEGs and MEGs) have been found to be very different. Certain rhythms are seen only in the former and some, in the latter while ECGs and MCGs are very much alike. For this reason SQUID magnetometers are especially promising in brain studies. Many important results have been obtained by such techniques.

The differences between EEGs and MEGs are not necessarily obvious. Thus, in the alpha rhythm, i.e, in 8 to 12 Hz oscillations which are characteristic of wakefulness in a calm state with the subject's eyes closed, the magnetic and electric fields appear simultaneously (Fig. 28) and their amplitudes are correlated, that is, a subject who produces a larger electrical alpha-rhythm signal also generates a larger magnetic signal. True, no such unambiguous relation was found in patients whose rhythmic activities are disturbed.

In comparing the electro- and magnetoencephalograms it should be remembered that unlike other organs the brain is practically encapsulated in a bone tissue whose electrical conductance is much lower than that of the skin and the brain itself. Besides, the natural orifices of the skull make the paths of electric currents more complicated. As a result, the pattern of potentials on the surface of a human head is a complex superposition of spatial distributions of signals from fairly distant sources inside the brain. The magnetic sensor, however, chiefly responds to stronger currents in the region of bioelectrical activity, which are, and this is also very important, specifically oriented relative to the SQUID magnetometer input coil. The advantage of magnetographic methods lies in recording the signals undisturbed by other activities and coming from a specific source inside the brain. This aspect is most interesting for research and diagnosis purposes. Thus, magnetographic studies of epileptic patients

revealed the sources of pathological activities in the brain while EEGs sometimes failed to show the characteristic spectrum of epilepsy.

The advantages of magnetic techniques are most obvious in studies of brain responses to various tactile, visual, and acoustic signals. In many laboratories around the world these so-called *evoked magnetic fields* (EFs) have been found

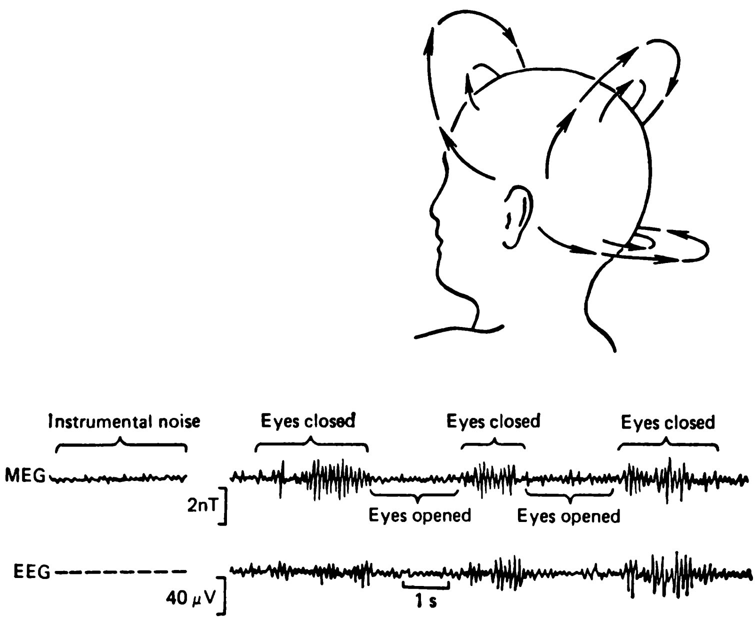


Fig. 28. Distribution of the alpha-rhythm magnetic field around a human head and the alpha-rhythm representation on magneto- and electroencephalograms

The brain activity with the subject's eyes closed, and its suppression when the eyes are opened, are obvious

to be rather simply structured and to be used for localization of the source of biological activity in the brain cortex. Some EF sources can be fairly accurately modeled by a current dipole, or a miniature battery with the poles close to one another. The dipole position, its depth inside the brain, direction and magnitude (the product of the current density

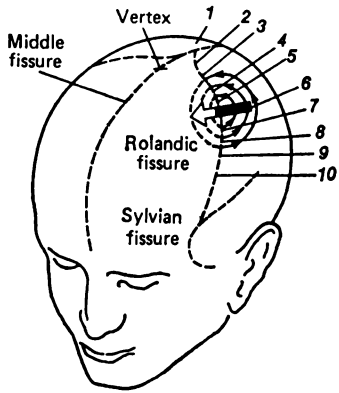


Fig. 29. Current dipole and its magnetic field (concentric arrows) forming when the little finger on the right hand is electrically stimulated

Projection zones of sensitvie receptors: *1*—leg; *2*—torso; *3*—arm; *4*—wrist; *5*—hand; *6*—little finger; *7*—thumb; *8*—face; *9*—lips; *10*—tongue

by the active volume) can be determined magnetographically. In response to visual stimulation a current dipole is formed in the occipital part, and to an acoustic stimulation, in the temporal part of the head. Stimulation of the little finger on the right hand causes the formation of a dipole normal to the central fissure in the left hemisphere (Fig. 29). This dipole is in the projection zone of sensory receptors associated with various parts of the body, exactly where the neurosurgeons detected the "representation" of the little finger. Magnetography detects without surgery the exact spot in the cortex where the data from sensory organs arrive to be processed. Thus, the current dipole associated with the

little finger is two centimeters above that associated with the thumb. Magnetic techniques will hopefully confirm or determine the position of other functional centers, something which EEGs certainly cannot do.

The relatively simple shape of some EFs makes possible reliable neurophysiological experiments. For example, the brain magnetic fields generated in response to a periodic pattern of dark and light strips (grating) on the oscilloscope screen were studied. This kind of stimulation in studies of visual perception is quite widespread and follows from the advanced theories on pattern perception. The amplitude of the magnetic signal in response to such stimulation has been found to be twenty times that in response to a single flash. Displaying such a pattern periodically (eight to twenty times per second), the time of signal propagation along nervous paths from the eye to a specific point in the cortex can be determined by measuring the delay time of the magnetic response.

Signal propagation is not a passive process. The information is processed in different parts of the brain and this "active" delay time τ may explain the nature of this processing. The delay time increases with the density of the pattern, or with the pattern "wave number" N measured in the number of lines per degree of the field of view (Fig. 30). This implies that the brain responds faster to a stimulus if the fragments are larger. This finding is, however, true only if the frequencies of the grating display are below 20 Hz; at higher frequencies the signal processing mechanism is quite different and the delay time is independent of N. The same boundary frequency was also found in signal propagation from tactile stimuli.

The measurements of magnetic responses to a visual stimulus and comparison of the characteristics of this response with the conventional stop-watch studies of man's response

to a grating pattern made it possible to divide the response time t_r into two components, the signal analysis time (which depends on the pattern periodicity) and the actuating impulse transmission time. Comparison of the scales on the right

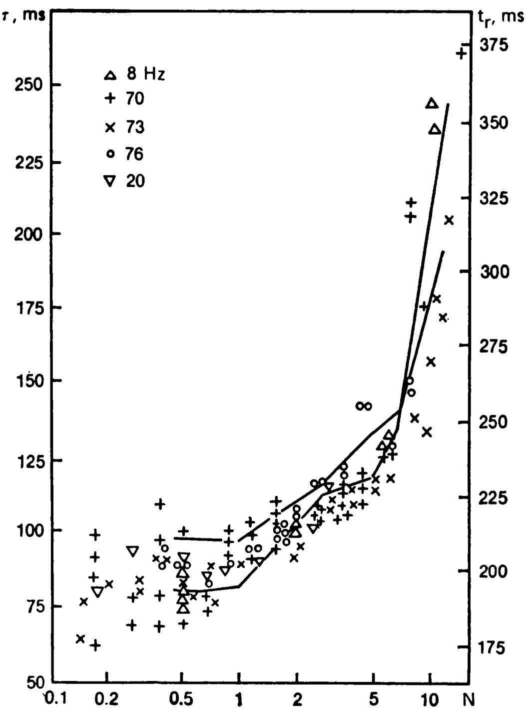


Fig. 30. Delay time of magnetic brain response (left-hand scale, discrete marks) and full time of human response (right-hand scale, solid curves) as functions of the stimulus density in terms of the number N of lines per degree of the field of view

and on the left in Fig. 30 shows that the transmission time amounts to about 110 ms, whatever the stimulus.

The measurements of the active EF delay time made it possible to compare the response time of brain hemispheres exposed to a visual stimulus. The brain is linked with the visual sensors in a way different from links with other senses. The left hemisphere receives signals from the right half of the field of view of both eyes and the right hemisphere, from the left half. In most individuals the delay time is the same for both hemispheres but in some the difference between the delay times in the hemispheres was as large as 0.1 s. This finding may prove to be clinically valuable, for instance in early diagnosis of sclerosis.

The magnetic hardware localizes with increasing precision the current dipoles associated with specific kinds of nervous activity of the brain and differentiates the signals. The active area in the cortex was found to move 1 cm into the so-called Sylvian fissure as the pitch of the sound increased from 200 to 5,000 Hz; when the frequency changed smoothly, the gradualness of the movement was observable.

Accurate measurement of the nervous activity region accompanying the stimulation of a specific sensory organ makes it possible to draw maps, "somatotopic" for tactile stimulation, "tonotopic" for audio stimulation, and "retinotopic" for vision.

These maps may facilitate the understanding of data processing in the brain and the staging of more involved neurophysiological experiments with healthy subjects without much inconvenience to them. Since we have been dealing thus far with the simplest manifestations of nervous activity and since more complicated processes in the brain that are also mapped magnetographically will most probably be highly individualized, these contactless magnetometric methods seem to be very promising.

Magnetography penetrates beyond the cortex to deeper brain structures and studies processes more involved than responses to excitation of the organs of senses. Magnetic fields have been measured that appear when man is about to act. The source, again dipole-like, forms one second (*sic*) in advance of, say, a leg movement; it is located in the vicinity of the hippocamp, region below the cortical hemispheres. When the individual intends to move his right leg the dipole is turned 45° leftwards, and when he is to move his left leg, rightwards.

There are two reasons why most manifestations of neuromagnetic activity are describable by a current dipole. First, this kind of excitation seems to be characteristic of those relatively simple nervous processes which were reported in first papers on biomagnetism. More involved neurophysiological phenomena are probably controlled by a more involved system of magnetic sources. Second, with the existing SQUID magnetometers the detection of even a dipole source is a very complicated process and studies of more involved processes are technically very difficult. Fortunately, supersensitive magnetometry has not exhausted its potential. New SQUID manufacturing technologies in the microelectronic industry, development of compact cryogenic hardware, and the increasing power of advanced computers ensure increasingly extensive use of SQUID magnetometry in studies of the human brain.

A set of about one hundred sensitive elements simultaneously monitoring the magnetic fields at various points around a human head is now quite a realistic proposition. Computer processing of such data will yield a map of field sources distributed in the entire brain. Such a system is very much like the existing computerized X-ray and NMR tomographies, the former providing a full picture of distribution of matter density in the brain using the data on X-ray ab-

sorption and the latter, the distribution of certain chemical substances. In the future the magnetic methods may yield a three-dimensional picture of the electric activity of the brain.

Magnetic studies of the brain have been under way only a few years but even the first findings show the immense potential of this method. Biomagnetism has not only become a major field of the biological science but it also blazed the trail for other applications of supersensitive magnetometry.

Together with the transistor and the laser, the SQUID demonstrates the utility of quantum mechanisms whose brainchildren they are and which once seemed so abstract.

Radio Frequency Emission of Human Body and Medical Diagnostics

V. S. TROITSKY

All bodies whose temperature exceeds absolute zero are known to emit electromagnetic radiation in the entire wavelength band. The intensity of this radiation, usually referred to as thermal, is described by the Planck radiation formula.

For not very low temperatures and rf radiation intensity is strictly proportional to the body temperature and its emissivity. If the latter is known, the body temperature can be determined indirectly by remote measurements.

Such methods are extensively employed in the visual range to measure high temperatures in industrial processes and

in astrophysics. The temperature can now be measured inside media that are transparent to radio waves. In this way the temperature distribution in the solar plasma is determined. The shorter the wavelength of the solar rf radiation, the deeper the layers are whose temperature can be measured (in fact, tens of thousands of kilometers). This property of radio frequencies has also been used in measuring the temperature conditions in the upper crust of the Moon. There, unlike the plasma atmosphere of the Sun, longer waves are obtained from larger depths. Radio frequency measurements at different wavelengths, from centimeters to meters, have revealed that Moon's depths are hot. The lunar radio frequency spectra in a wide range of frequencies can also provide an insight into all the physico-chemical parameters of the matter in the upper crust (up to the depth of ten meters) of the Moon. The findings of the remote sensing of the upper layers, the properties of its substances, and the temperature conditions obtained in 1967 were confirmed by direct examination of lunar samples and measurements on the Moon itself. These studies reflect the general principle: the multiband electromagnetic radiation generally reveals the properties of the emitting bodies.

In astrophysics remote studies of objective are a necessity because direct measurements are out of the question. In recent years, however, remote techniques have been applied even in the cases where the objects were quite accessible. One impressive example of this is remote sampling of natural formations on our planet, in particular of its mineral resources. The electromagnetic radiation supplies data on the properties of the Earth's surface (dry land and oceans), the atmospheric parameters, and the status of farmland. By measuring the spectrum of the natural atmospheric radiation from satellites or from the surface of the Earth, it is possible to determine the meteorological parameters such as the tem-

perature, pressure, and humidity as functions of altitude, the integral water content of the clouds, etc. The principle of multiband remote measurement of such parameters is the same that was used in lunar studies: the radiation at different frequencies is received and analyzed, and the values of the parameters are calculated for different altitudes.

A logical extension of this research was the studying of the thermal rf emission (the natural rf noise) of biological objects, primarily the human body and its various systems and organs. Now, the temperature of internal organs is measured in this way in man and animals.

This research was encouraged by medicine which now practises on an increasing scale the methods of tissue cooling and heating. It is therefore important to monitor, for instance, the temperature inside a cancerous tumor when it is destroyed by heating. The methods whereby the temperature of internal organs can be measured remotely without affecting the living tissue are obviously very promising. The overall temperature of human body has long since been a major indicator of sickness. Many diseases such as local inflammations manifest themselves in changes of the temperature of certain parts or organs. In a healthy organism certain temperature distribution is maintained in different organs and systems. Thus, the brain has a temperature of 38 °C while the forearm muscle, only 36.6 °C.

Malignant tumors increase the tissue temperature by 1.2 °C while blood circulation disturbances decrease it.

The temperature response of an organ to drug treatment is also diagnostically significant in that its malfunctions can be detected.

For these reasons physicians, biologists, and biophysicists show a tremendous interest in using this contactless, painless, and harmless method of measuring the temperatures deep inside man and animals.

* * *

Remote measurement of human body temperature in the IR band has now reached considerable sophistication. This radiation has a wavelength of about 10 microns; it escapes from a depth no greater than 0.1 mm, and thus shows the temperature only in that skin layer. In this method the so-called skin brightness temperature is measured which, however, is somewhat different from the actual value. This technique gives merely a "topographic" picture of the body surface temperature which is weakly, if at all, related to the temperature of internal organs.

The heat radiation in the centimeter and decimeter wavelength range arrives from fairly deep layers and its intensity is unambiguously related to the temperature of the radiating areas. By measuring the intensity, the temperature at a certain depth inside the body can be estimated. This depth depends on the electric properties of the medium such as the dielectric constant and conductivity.

The radiation of the human body in the centimeter and decimeter ranges was measured in the early days of radioastronomy in late 1940s and early 1950s by using the radiometers developed in the Radiophysic Research Institute, NIRFI, in Gorky for radioastronomic purposes. The radiometer sensed a hand brought close to its antenna (to the open end of a waveguide). The thermal radiation of the hand in the rf range indicated a temperature which was much higher than that of the environment. The medical potential of the method was not understood at that time, however; what is more, no hardware was available for accurate measurement of a weak rf signal against the background of electronics' noise.

The first experiment which demonstrated the feasibility of measuring the temperature deep inside the human body

was carried out in Sweden in 1972. A radiometer antenna probe was fixed to the skin above the stomach area and the rf intensity was recorded at a wavelength of 30 cm; then the subject drank some cold water, and the intensity immediately dropped with the temperature inside the stomach. This experiment showed that what was recorded was indeed rf radiation at $\lambda = 30$ cm from deep inside the body, possibly from the stomach. The conventional radiometer used in the experiment could, however, only detect changes in the local temperature rather than measure it.

The first attempt to measure the temperature deep inside the human body for medical purposes was made at Massachusetts Institute of Technology (MIT) in 1976. A conventional $\lambda = 10$ cm radiometer detected the radio frequency radiation from mammary glands of women patients in order to see whether early cancer diagnosis can be performed in this way. The antenna was in contact with the skin and the temperature difference between the two glands was measured. As mentioned above, the temperature of a cancer-stricken organ is higher. The task was simplified because for diagnostic purposes only the difference between the gland temperatures rather than the absolute values had to be measured. Still, the difference drowned in measurement errors and significant statistics was needed to make a final conclusion.

The basic difficulty was that at the interface of two media such as the body and the air some of the radiation is reflected back. The same is true for the body—antenna interface. If as little as one per cent of the radiation is reflected back, the error in temperature measurements may amount to 3°C.

The reflection is reduced by tuning the antenna to match it to the medium. If, however, the mismatches of the two antennae for the two glands differ by as little as 0.5 per

cent, the corresponding measured difference between the glands is 1.5°C. This is inadmissible because the entire temperature range of all organs and parts of the human body lies within the 32 to 40°C interval and the temperature variation in any particular area never exceeds $\pm$ (2 to 3) °C.

Consequently, for the method to work the measurement precision should be at least ± 0.1°C. The MIT experimenters failed to achieve this mark.

Similar research was started almost simultaneously in France and in the USSR, in NIRFI, Gorky, and in the Institute of Applied Physics (IPF) of the Academy of Sciences. The NIRFI researchers achieved the desired precision of the contact method and developed a radiothermometer operating at a wavelength of 32 cm. The IPF team measured the temperature difference by a conventional radiometer in the millimeter range in the Gorky Institute of Traumatology and Orthopedics.

This success was made possible, above all, by ideal matching of the antenna and the body. But even if this is achieved for a certain part of the body, in another area the matching conditions may be violated because the dielectric properties of the tissues vary in a fairly wide range.

The US researchers tried to overcome this problem by tuning the antenna every time to the local properties of the tissues or by measuring and using in the computations the radiation reflection coefficient on the body-antenna interface. The desired precision was not achieved, however. We approached this problem from a different angle. A special-purpose radiometer was developed in which all input elements of the circuit were in thermodynamic equilibrium at about the average human body temperature assumed equal to 36°C. The part of the signal which had been lost because of the incomplete matching was compensated for by the input noise associated with a temperature approximately

equal to the body temperature, reflected by the antenna. The error due to mismatch never exceeded 0.2°C.

The absolute reference source was salty water heated to a precisely measured temperature.

The radiometers were operational on various wavelengths and ensured highly accurate temperature measurements. Similar results were obtained by French researchers; their radiometers are in use in some Parisian clinics.

VHF tests of human tissues taken recently in several countries have revealed that electromagnetically the tissues fall into two distinct groups. In the one the dielectric constant is large, 60 to 80, and the decay of electromagnetic waves is very much like that in physiological saline solution; in the other the dielectric constant is small, five to six, and the decay is relatively low, equal to that of distilled water. The former group includes water-rich muscle tissues, the brain, and blood, which act as dielectrics at wavelengths shorter than 70 cm and as semiconductors at longer wavelengths. The latter includes fat and bone tissues containing little water; for them the dielectric-semiconductor boundary lies at a wavelength of 150 cm.

Radiation damping is usually described in terms of the depth from which the radiation arrives at the skin surface being attenuated by a factor of 2.73. This is what is called the penetration depth because at this depth a wave propagating inwards from the skin surface would be attenuated to the same degree. The penetration depth can be measured in laboratory by an external rf generator.

In tissue the wavelength is much shorter than that of the same radiation in the air (by a factor of about eight for the first group of tissues). For wavelengths shorter than 30 cm the penetration depth in a muscular tissue has been found to be approximately half the wavelength in the same tissue and in the fat tissue the penetration depth is two thirds

the wavelength in the same tissue. For a wavelength of 30 cm this gives 1.5 and 7.0 cm, respectively.

As noted above, it is desirable to channel all radiation arriving from inside the tissue into the antenna. This can be done by placing the antenna subcutaneously but the same result can be obtained in a painless way by applying to the skin a dielectric whose dielectric constant is equal to that of the body, and placing an antenna inside the dielectric. A rather crude but true picture of what is going on inside that part of the body is obtained in this way. Because the antenna is inside the dielectric and responds to a wave whose wavelength is a fraction of what it would be in the air, the size of the antenna is reduced by the same factor. Consequently, the maximal resolution, or the minimal possible linear dimension of the surface area which is covered by the antenna and under which the temperature is measured, is only four centimeters for the 30 cm wavelength (usually the antenna probe has a dimension equal to the radiation wavelength in the muscular tissue). Consequently, the radiometer measures the average body temperature inside a cylinder whose base is equal to the area of the antenna and the height (say, for measuring the temperature of the muscular tissue) is about half the wavelength in the antenna, i.e., it equals the penetration depth.

The depth at which the temperature measurement is taken is increased by increasing the wavelength. However, the resolution deteriorates fast.

An optimal compromise of the penetration depth and the resolution is probably achieved in the 30-cm wavelength. The antenna is still small but the measurements can be taken three to four centimeters deep in muscles and 12 to 15 cm deep in fat.

* * *

The 30-cm radiometer developed in NIRFI has been in use for years in the clinic of the Kirov Medical Institute in Gorky for medical diagnosis. In the clinic of nervous diseases A. V. Gustov, Ye. P. Semyonova, and V. D. Troshin have studied over 300 patients and hundreds of healthy subjects in an effort to unravel the thermal pattern of the brain and the effect of diseases on them; in particular, an impressive amount of data has been collected on temperature distribution in human body and the effect of blood circulation and various internal diseases on it.

The radiometric method has been found effective in studies of temperature fields affected by various factors, in particular by diseases. The radiometer is obviously a promising tool in biophysical research, for instance, in studying the energy transformation processes in an organism.

By measuring at several frequencies at once we obtain the temperature profile in the tissue. In a near future such multifrequency radiometers (which make it possible to "see" the temperature distribution in the desired part of the human body) will be extensively used in locating spots of increased or decreased temperature. Such a radiometer can be rightfully described as a radiothermograph because by moving the antenna over the body the three-dimensional distribution of the temperature inside the entire organism will be obtained.

The advanced electronics makes it possible to have a radiothermograph integrated with a microprocessor which could be held in one's palm and be capable of instantaneous data processing and displaying the temperature readings at specified depths after a two- or three-second contact with the body. Mass monitoring of people and animals can be organized in this way. Medical researchers will have

to find an accessible spot indicative of the general body temperature.

By using wavelengths of 1.5 to 2 meters the depth of probing could be increased 2 to 2.5-fold, albeit at a price of a poorer resolution.

Using decameter, kilometer, and still longer wavelengths may now seem fantastic but may hold a promise if the moderate deterioration of the resolving power is achieved. At these wavelengths the electromagnetic radiation emitted inside the human body could be measured at any depth. If all the wavelengths, from millimeters to kilometers, could be used, a system could be developed capable of taking the average temperatures in a layer of the desired depth or of the entire skin surface or, finally, of the entire body volume. This temperature "cross-section" will give a good quantitative picture of energy-transformation processes inside the body and will facilitate studies of the impact of various factors, such as the physical strain, on these processes.

A range of methods will hopefully be forthcoming shortly in which the natural radiation of a living organism in a wide range of wavelengths will be measured for research and diagnostic purposes. The now available radiometers will be widely applied in medico-biological studies and in medical practice. Studies of rf emission and rf noise in living beings will develop into a new scientific discipline.

Several Problems in Psychology

The Psychology of Cognition and Cybernetics

B. M. VELICHKOVSKY

The advent of cybernetics, or control engineering, has made a tremendous impact on psychology. Since early 1960s psychology concentrates on information acquisition, storage and utilization by man rather than the animal behavior and learning processes. Cognitive psychology came to existence [1] and gradually expanded its field from cognitive processes in the narrow sense (perception, attention, memory, thinking, and interpretation) to motivation, emotions, and even motorics because in all these areas the importance of human knowledge of man and his environment became obvious.

On the other hand, physiologists and psychologists such as P. K. Anokhin, N. A. Bernstein, and W. Köhler made significant contributions to the making of cybernetics. From the outset, logic was regarded as analysis of human thinking. In mid-19th century J. S. Mill and G. Boole were convinced that their logic systems described the laws of human thinking ("An Investigation of the Laws of Thought on which are Founded the Mathematical Logic and Probabilities" was the title of the latter's book published in 1854 describing the binary algebra which bears Boole's name). Thinking, speech, and intelligence are mentioned albeit often irrelevantly, in numerous current papers. This article will outline the history of changes in the analogies drawn between man and machine in the cognitive psychology itself.

Human Being as a Communication Channel

The first control engineering tool adopted by psychology was probably the statistical communication theory, more specifically, the formal way to estimate the amount of data in a message. In this light man was viewed as a communication channel with a finite throughput.

The new approach was almost identical with the studies of man's psychophysical potential by the engineering psychology during World War II. The information theory seemed to many psychologists to be a general-purpose tool, a kind of Laplacian "world formula" which was to provide a uniform explanation of various psychological phenomena (mostly known to psychologists since late 19th century) such as the impossibility to memorize and reproduce more than five to seven unrelated objects shown for a short time (letters, numbers, syllables or words); selectivity of attention, or impossibility to perceive equally effectively two different messages; oscillations of attention, or impossibility to follow some object, such as the target on the radar screen with undiminished "vigilance"; psychological refractoriness, or delay of a motoric response to a stimulus which follows a preceding one in less than 0.25 s.

Probably the most remarkable fact of this kind was the retardation of choice when the number of options and thus the signal uncertainty increased. Back in 1885 J. Merkel found that the response time was linearly dependent on the logarithm of the number of possible stimuli. The same result was obtained in early 1950s by W. Hick who attributed this to the dependence of the response time RT on the average amount of data

$$RT = a + bH,$$

where a is a parameter specified by the time of data transmission at the channel input and output, b is a quantity inversely proportional to the channel throughout, and H is the average amount of data to be determined from formulae of the statistical communication theory. This relation known as Hick's law remains true no matter how the amount of data is varied, which may be by varying the number of options, or of the absolute probabilities for the same number of options, or by introducing various conditional probabilities of signal sequences.

D. E. Broadbent, a disciple of the well-known British psychologist Sir Frederick Bartlett and a student of informational constraints on memory and attention, published in 1954 an article "A Mechanical Model for Human Attention and Immediate Memory" where he pioneered in describing attention as an all-or-none filter of sensory data at the input to the readily accessible memory treated as the central channel whose throughput is limited. Later the same ideas were extended in a book [2].

Papers on psychology viewed by the statistical communication theory were abundant in late 1950s and early 1960s. At that time, however, it was obvious that the information-theoretic approach failed to live up to the promise of changing the conceptual tools of psychology in the way that Galilean or Copernican theories changed physics.

First, the laws had to be amended by numerous addenda and qualifications which recognized the factors of significance, purposefulness, and likelihood of various situations. In those years the most important problem faced by the engineering psychology was the relation of signals to the subject's responses. The speed of response was found to increase when an acoustic signal from the right had to be responded to with the right hand. This effect could be

explained by tracing the propagation of data along the anatomical channels, from the right ear to the left cerebral hemisphere which governs chiefly the right part of the body. This explanation is, however, questionable. If the subject is asked to cross his arms, then his left-hand response to signals from the right becomes faster. The immediate spatial proximity of the signals and responses is thus essential. Therefore, the researcher has to determine how the environment, the signals, and the body circuits are represented (mapped) in the human mind.

The choice (response) time determined in subsequent researches did not fit Hick's law. The parameters of resultant formulae proved different for various types and combinations of signals and responses. In some cases, especially for natural sequences of signals and responses, no clear-cut dependence of response time on the data influx was found. The interpretation of these facts in terms of the Hick's law leads to a fallacious conclusion that "human throughput" is infinite. These studies confirm that human adaptability is nearly infinite. In one experiment, which took five months, there were over 45,000 trials but the response time continued to decrease.

Short-term memory was found to be constrained in the subjective arrangement of the knowledge in "pieces" whose sizes increase with learning, rather than in terms of data measured in bits. In the same way, a combination of sensory attributes, which in logical terms does not change the uncertainty of the signals, significantly improves the throughput. In the case of single-dimensional signals which vary only in color, brightness, or size the subject can transmit 2.75 bits, which are equivalent to unmistaken recognition and classification of about seven stimuli. If all the three features vary in a fully correlated (redundant) way so that in formal terms there is just one dimension, the

amount of data increases to 4.11 bits, which is equivalent to the recognition of 17 stimuli.

The understanding that man is not a passive communication channel and actively "processes the data" by building internal models, or representations, of the environment signified the advent of cognitive psychology proper in place of mere data processing. The cognition processes were regarded in the light of their consistence with the functional architecture of the computer.

The Computer Metaphor

This approach opened new vistas for psychology. W. Wundt, the founder of experimental psychology, and his contemporaries assumed that conservation of energy called for stringent psychophysical parallels. However, a computer which consumes very little energy is capable of controlling huge machinery. Even though it would be difficult to uncover the actual processes behind some psychic activities such as perception of Rembrandt's masterpieces, a flowchart of cognition can be easily imagined which describes the data processing in a computer and culminates in a proper response.

The extensive use of computers and the computer metaphor left yawning gaps in explanations of the mental functions. Thus, learning which takes hours, days, and years rather than milliseconds or seconds was initially disregarded. The fact is that first-generation computers could not learn because their potential was rigidly prescribed by the architecture and software; rather, they successively processed digital symbols and the active processor was separated from passive external memory. Data could not be handled outside the processor where the memory

was very small. Passive memory was, in contrast, much larger and contained both the data and encoded processing routines. Accordingly, similar features were detected in human cognitive activity.

Numerous experiments established the decisive role of repetition for long-term memorization of verbal or easily verbalizable knowledge. If, once the subject sees it, some task should be performed which requires saying internally certain words (e.g., subtracting three from a fairly large number), the probability of correct reproduction approaches zero after 10 to 20 seconds. G. Sperling and then other researchers came to a conclusion that after a short display visual information is retained for about one third of a second as a relatively complete sensory pattern, an "icon", following which it disappears or is transformed into another, most probably, verbal representation. The assumption that repetition is essential for the data to be stored in long-term memory became known as the "verbal loop hypothesis."

All these findings were explained in early 1970s in models which consisted of three sequential data processing units: sensory registers ("iconic" or "very short-term visual" memory); primary memory (short-term memory of limited size where data are retained through repetition); and secondary memory (long-term semantic memory where the amount of passively stored knowledge is immense). Such a model is easily seen to represent the architecture of a computer and be at the same time quite conventional, for primary and secondary memories were differentiated by psychologists as far back as in late 19th century. They believed that continuous retainment of representations and ideas within the consciousness sphere was primary memory while repeated return of the representations into the consciousness following some interval was secondary memory. Conse-

quently, primary, or short-term memory, is a remarkable formation which has much in common with consciousness, a communication channel, and a computer processor.

However, data were coming that structural models, such as the one above, were not as general as they were thought to be. In particular, in the case of data arranged by objects, as is the case with picture slides, a purely perceptive description which does not require verbal encoding may prove quite long-term. Verbal encoding has the advantage of relative accessibility for arbitrary reproduction and communication. In other situations, however, active visual and evaluating emotional forms of memory may be chiefly used, as in the recognition of objects, landscapes, faces, and tones of the voice and in the transfer and sophistication of various know-how, from reading to cycling skills. Memorization in such tasks is essential because it facilitates detection, adjustment, and revival of earlier developed systems of psychological operations.

Individual strategies of tackling cognitive tasks were found to be surprisingly diverse. The explanation of data processing by man within the framework of even a large block diagram looked like description of a statistically average family: a husband, a wife, and 2.5 children. In typical psycholinguistic task the subjects test the sentences which describe a three-dimensional scene. The subjects were assumed to tackle such tasks by employing verbal encoding and short-term memory. However, the correlation of solutions with other tests of verbal intelligence rarely exceeded 0.4. Experimental analysis showed that those tasks could be performed, in addition to comparing two verbal descriptions, by transforming the sentence itself into a three-dimensional model and then comparing the model with the scene. The subjects control arbitrarily the use of various forms in which knowledge can be represented,

even though as people become older the probability of obtaining a solution by the latter strategy is reduced.

The subsequent modifications of structural models of cognitive processes became so cumbersome that the explanatory power was lost. The growth in the number of models which could possibly be distinguished by factor analysis got out of hand; hard scientific facts were acquired at a much more modest rate. Two or three decades ago, when concepts were borrowed on a wide scale from computing technology, theory of servos, mathematics, the statistical theory of communication, and structural linguistics, the relative unambiguity of these concepts in their original fields was believed to ensure their equally stringent use in psychology and to have a disciplinary effect, whenever necessary, on the psychologists themselves. These hopes proved futile. Thus, the once uniform *mnema*, the substance of memory, decomposed into scores of units filled in with various "attributes", "markers", "patterns", "names", "tags", "first- and second-order isomorphisms", "holograms", "nodes", "surface and deep structures", "traces", "vignettes", etc. G. Claxton described this situation in the following way: "We are like the inhabitants of thousands of little islands, all in the same part of the ocean, yet totally out of touch with each other. Each has evolved a different culture, different ways of doing things, different languages to talk about what they do. Occasionally inhabitants of one island may spot their neighbors jumping up and down and issuing strange cries; but it makes no sense, so they ignore it" [3].

A most hotly debated issue in today's cognition theory is whether the representations employed in thinking processes are analogous or propositional, i.e. whether the patterns are "picture-like" or they are logical propositions. This debate is traceable to the existence of two kinds of

computers. The debate is as far from settlement as ever and becomes so esoteric that people would have to "read each other's minds" for mutual understanding. What is enlightening is that the points of view in this debate correlate with the specifics of visual perception of the participants and with their professional backgrounds; the adherents of the picture metaphor tend to represent the humanities and those of the propositional representation, mathematics, programming languages, and neurophysiology.

The arbitrariness of models is the most serious handicap of cognitive psychology, especially so because psychological experimentation is not a very accurate tool in checking theories. As a result, the population of formal models grew over the last decades much faster than the rate of their testing. Besides, arbitrary interpretations do not require any research. To put it differently, formal modeling for the sake of modeling was allowed to continue unabated.

The Computational Approach: Cognitive Psychology or Cognitive Science?

Some authors assert that any psychological theory should be explicitly developed as a computer program. The protagonists of this approach tend to go even farther. They feel that the psychological processes should be literally understood as computing processes, in fact as manipulation of abstract symbols. These researchers seem to be fascinated by the potential of computers.

This approach came into existence with cognitive psychology and was regarded for some time as its integral part but its key objective has always been computer simulation of various cognition processes. The approach was obviously enhanced by the advent in mid-1950s of advanced program-

ming languages, by research in artificial intelligence, and by the resultant avalanche of programs simulating problem solution. The most important landmarks of today seem to be the development of integral robots and vision systems incorporating elements of artificial intelligence and the consensus that knowledge may be represented in memory as operations, or procedural knowledge, as well as static structures of the data-base, or declarative knowledge.

This new stage of research which interfaces the cognition psychology and control engineering was launched in early 1970s by papers summarizing the results of computer simulation of proving geometrical theorems, solving cryptoarithmetic problems, and chess programming. The fundamental assumption was that cognitive processes were computing processes and the basic conclusion was that they were arranged as productions, or as a system of condition-operation connectives. This model of thinking was believed to function so as to balance the data arriving from the environment ("external memory") with that generated by the production. As a result the characteristically human unpredictability of behavior was simulated.

In recent years attempts have been made to replace cognitive psychology with a "cognitive science" which would combine the empirical knowledge of psychological laboratories with the theoretical findings of computer vision, theory of interactive systems, and artificial intelligence.

The objective of the computing approach is to develop programs which would perform the functions of human cognitive activities, above all, intelligence. Control engineering tried, however, to supplement rather than imitate the human potential. What the computer does easily may be a difficult chore for man. On the other hand, certain activities are beyond the computer's reach. Thus, man likes cutting through the fallacies of fuzzily stated problems.

Interesting results are obtained when such peculiarities are taken into account. V. S. Pereverzev-Orlov has developed an interactive Doctor's Assistant system which summarizes the views of many physicians on the symptoms of some diseases. A dialog of a doctor and a computer results in a diagnosis. In this system the specific and the abstract aspects of intelligence are separated; the former remaining in the physician's mind and the latter existing as a program.

Unfortunately, meaningful recognition of psychological data is a rare occasion in the computing approach. Its followers are usually convinced that all forms of human knowledge are reducible to predicates of a hypothetical "language of the thought" which is essentially very much like the computer autocode.

The Systems Research Strategy

The creation of a new scientific discipline which would recognize and incorporate the interface between control engineering and the cognition psychology could undoubtedly accelerate to an even higher degree the research on acquisition, storage, generation, and utilization of knowledge by man. It is important, however, that the "cognitive science" not become an "artificial science" ignoring the significance of social factors in the development and the laws of the human brain functioning. The field of research should be expanded to incorporate kindred disciplines such as the children and adult psychology, social psychology, neuropsychology and neurophysiology, linguistics, etc. Memoirs of historical figures of the past may also prove helpful.

The researchers who developed a technique to rank the goals of statesman [4] have modeled the specifics of think-

ing in various, notably critical, situations. This is a pioneering attempt to model the evaluation of the situation and choice of the behavior strategy in actual conditions.

The data of kindred disciplines, if properly used, could significantly reduce the arbitrariness in explaining the findings of experimental psychology. In the framework of the systems approach to psychology such integration should result in identification of invariant laws of mental life and express the conceptual tools in mathematical terms [5].

Some lines of psychological research emphasize the logical fundamentals of human cognition (e.g., "the operational concept of intelligence" in the works of J. Piaget, the Swiss psychologist) but most psychologists are critical of the view that there are no qualitative differences between various forms of representing the knowledge of self and the environment. It is difficult to believe, for instance, that even very simple reasoning can in actual conditions proceed by the rules of formal logic alone. Some varieties of non-conventional logic systems that allow for the specific features of human action, in particular, its purposefulness ("intentionality") may prove very successful.

To describe in most general terms the structure of the human cognitive sphere in the light of psychological findings and cybernetic ideas, an impressive amount of relatively specialized procedural knowledge would have to be assumed. This knowledge is generated as a result of automating the practical and cognitive actions under typical conditions such as reading typical texts with their graphical, statistical, and semantic specifics.

The cognitive automatisms are always ready for action. When the situation they are prepared for arises (e.g., when a familiar word appears in the field of view), they perform independently of (sometimes in conflict with) the arbitrary intentions and without the mind being aware. Besides, since

the automatic processing is performed by subsystems, or modules, their activity has no impact at all on the operation of the parallel subsystems. The automatisms outline the spectrum of possible interpretations of a situation and ways to behave in it. This makes all the difference between the automatisms and the processes of comprehension which are to limit the degrees of freedom of possible interpretations to a single (at the time) understanding which explains in the simplest possible terms the maximal amount of data identified by the cognitive modules.

Various psychological disciplines are in possession of numerous facts which provide a detailed picture of this procedural level in the organization of human consciousness. We will limit ourselves to the neuropsychological data. The speech processes and awareness are widely believed to be controlled chiefly by the left cerebral hemisphere while complex perceptions, for instance of faces or musical pieces, and spatial orientation, by the right hemisphere. When some central structures of the brain are injured, gaps, so-called scotomas, occur in the visual field. Even though they do not perceive it, the subjects correctly direct their eyes at the object in the scotoma zone, are capable of pointing their finger at it, and, according to indirect evidence, can approximately determine what the object is intended for. But when he is told to describe what he sees, the patient fails to recognize the object. In one injury of neuropsychological mechanisms, phonematic dyslexia, the patients cannot read auxiliary and relatively rare words while frequently used words are misread. Thus, Belgium is read as Holland and north as east. One patient who was shown a card with the given name of her husband said after a minute's pause, "Looks like a necktie, like that of my husband's".

Whereas cognitive automatisms act as flowcharts of acti-

vities, comprehension acts as conceptualization of these flowcharts in which relatively independent cognitive modules are integrated into a more or less complex semantical network. The conceptualization transforms the procedural forms of knowledge into procedural declarative structures, declarative in the sense that they are described as symbols (characters) and can be used in various communication processes (or be declared). The knowledge is conceptualized as speech develops and, therefore, has social origins. According to L. S. Vygotski and J. Piaget, it is the representation of knowledge as characters that makes human thinking possible. Before them P. Janet showed that the "symbolic function" alone made it possible for man to keep track of two opposing "activities", for instance to treat a part as such, never losing sight of the whole, be aware of the direct and figurative significance of a phenomenon, etc.

A major role in conceptualization of knowledge is played by the so-called primary concepts which act as links between the three basic spheres of human knowledge, procedural, pictorial, and verbal. Primary concepts such as a table or a dog represent, first, the habitual images of such objects and, second, determine the relevant behavioral patterns. Furthermore, these words find their way into a child's vocabulary earlier than words denoting concepts of higher or lower ranks in the conceptual hierarchy (such a "furniture", "mammal", or "sheep dog") do. Children do not consciously process their experiences and so cannot control their behavior until they possess conceptual tools for mental modeling of the experiences. The ability of orientation and movement in an environment is developed long before the child becomes able to imagine and express that environment in a symbolic (verbal or pictorial) form. Conceptual structures seem to form the "space" where the subject's thought can act.

In addition to conceptual structures that identify a concept with a semantic class and express the relations of this concept with other representatives of that class, there are higher-rank structures, which are operations determining and transforming the relations between concepts, including relations between concepts of different classes. These operations may be referred to as cognitive metaprocedures. Some of them, such as formation and mental rotation of images, make it possible to utilize pictorial components of conceptual structures while others, such as reproduction and reasoning, to utilize chiefly or exclusively verbal structures, still others (such as orientation and search for analogies) are more universal. The latter probably add up to what is known as general intelligence.

A most general classification of metaprocedures would amount to separating the heuristics of thinking from semantic syntactical rules. The latter lead to a practically infinite number of propositional representations which include empirical knowledge and convictions whose truth value is not contained in the organization itself of basic conceptual structures such as the proposition that a dog is an animal. The heuristics of thinking which is widely known from research in artificial intelligence as well as from psychological studies includes the termination of intellectual activity so as to avoid vicious circles. An example of this is the psychological reaction to questions such as, Who shaves the barber who shaves whoever does not shave himself?

The metaprocedures dictate the strategy and tactics of thinking processes which on every occasion proceed against the background and to the accompaniment of emotional states which are as dynamic as, but more comprehensive than, the thinking processes themselves. By changing with the weakening and restoration of conscious observations,

emotions control to a tremendous extent the cognitive activity. Indeed, any situation where the available knowledge and habits are insufficient for making a decision induces strain and anxiety. Decision making which takes much intellectual effort and a lot of time is out of the question unless will power is sufficient and motivation is stable. If the problem is resolved, the satisfaction, pride, and triumph may announce this even before the truth or it is confirmed by consistent rational analysis [6]. The significance of this "esthetic heuristics" has been the subject of many papers (recall Richard Feynman's remark that "truth is recognizable by its beauty"). The integration of emotional states into conscious control explains their bearing on the intellectual organization of the personality. When anxiety turns into panic, joy into ecstasy, and anger into fury, both the conscious control and the affect-intelligence interaction are lost.

Research on cognitive mechanisms has been influenced by all basic evolutionary phases of cybernetics. The fruitful dialog between psychology and cybernetics has just begun. A science of cognition which would integrate cybernetics and psychology will not emerge until some time in the future. The two sciences can cooperate now in numerous fields, above all in what can be, somewhat paradoxically, referred to as "natural artificial intelligence".

References

1. Величковский Б. М. Современная когнитивная психология. М.: Издательство МГУ, 1982.
2. Broadbent D. E. Perception and communication. Academic Press, London, 1958.
3. Claxton G. Cognitive psychology: A suitable case for what sort of treatment? In: Cognitive psychology. G. Claxton, Ed. Routledge, London, 1980.

4. Луков В. Б., Сергеев В. М. Опыт моделирования мышления исторических деятелей. В книге: Вопросы кибернетики. Логика рассуждений и ее моделирование. Под ред. Д. А. Поспелова. М.: ВИНИТИ, 1983.
5. Ломов Б. Ф. Методологические и теоретические проблемы психологии. М.: Наука, 1984.
6. Тихомиров О. К. Психология мышления. М.: Издательство МГУ, 1984.

Subconsciousness and Superconsciousness

P. V. SIMONOV

Any discussion of what human mind cannot comprehend would be pointless and unproductive until the sphere of consciousness is identified. The physiologists who concentrate on the higher nervous activity believe that the process of comprehending and the possibility of communicating the acquired knowledge to other members of society are two aspects of the same phenomenon. To recognize something is to acquire the potential to communicate this knowledge to another, not necessarily in words, for jestures, drawings, or melodies may also do the job. Incidentally, it is only in this way that the doctor decides whether the patient is conscious and whether his consciousness is normal or has pathologically changed.

According to the latest findings, to recognize an external stimulus, the gnostical zones of the neocortex have to communicate with the motoric speech area in the left (in right-hand) hemisphere. The classical research of A. R. Luriya [1], the discovery of unconscious conditioned responses by G. V. Gershuni [2], R. Sperry's studies (for which he was

awarded a Nobel prize) of split-brain patients, and the subsequent research of E. A. Kostandov, V. P. Deglin, N. N. Bragina, T. A. Dobrokhotova, and others [3] were very important breakthroughs in basic neurophysiological research of human consciousness.

The identification of the consciousness makes it possible to separate what man recognizes and what he does not recognize in the brain activity. If a subject lists parts of a picture and some time later names those that he did not mention in the first description, unconscious perception and involuntary memory have obviously been at work. The millenia of human history suggest that there is a difference between the military science and the art of war. There is something in military activities that can be formulated as rules and something that cannot be taught. The art of war, like any other art, has a certain technology and know-how at its disposal but some element in the art of military leaders cannot be formalized and transferred to others as a rational decision because what the leader is aware of is only this decision, the culmination of a creative process.

In the immense sphere of the psychologically unrecognizable at least two groups of phenomena have to be distinguished. The one includes whatever was recognizable or could be recognizable to a certain degree. First of all these are habits which became automatic and so unrecognizable as such, and motivational conflicts which have been squeezed out of the conscious sphere and cannot be detected without special psychiatric techniques. These phenomena will, following established traditions, be referred to as the subconscious.

The subconscious includes deeply rooted social rules which are felt as the "voice of conscience", the "call of the heart", the "sense of duty". The assimilation of exogenous social rules makes them unexpectedly imperative. "The

court of men can be easily despised" wrote the great Russian poet Alexander Pushkin, "one's own judgment can by no means be despised". "Conscience is what stops me although nobody is looking and I can't be found out" (V. C. Korolenko). "Conscience is the memory of society digested by one person" (Leo Tolstoy). The interpersonal origin of conscience is felt in the word itself which implies shared knowledge.

Freudian "super-Ego", obviously different from biological urges, stays entirely in the sphere of subconsciousness and cannot be viewed as an analog of superconsciousness which will be discussed below*

The subconscious also includes those intuitive actions which do not generate new information but make use of only the available information. A good physician may diagnose a patient at a single glance but is not necessarily able to explain what features in the patient's appearance led him to the conclusion. Likewise, the pianist has long since ceased to think of the action of each finger.

The earlier experience such as a set of motoric habits, knowledge of symptoms, rules of social behavior, etc. is not the sole channel which feeds the subconsciousness. There is also a direct path, uncontrolled by the consciousness. This is imitational behavior. Indeed, the example set by adults and children of the same age shapes the child's personality more than explanations of the utility and social values of various activities.

In the course of evolution subconsciousness developed as a means to protect the consciousness from overloading.

---

* According to Freud, "super-Ego" represents in the individual's psychology the requirements and taboos of society. A conflict between biological urges ("It") and the censorship of "super-Ego" activates the mechanisms of psychological protection. If these are ineffectual, neurotic diseases develop.

Be it the motoric habits of a pianist, driver, athlete, etc. which can be successfully implemented without participation of the consciousness or a motivational conflict, the subconsciousness provides a protection from stresses.

Subconsciousness stands guard of what has been thoroughly assimilated, be it an automatic habit or a social rule. Conservatism is a most characteristic feature of subconsciousness. It makes individually acquired habits (conditioned reflexes) as imperative and as rigid as unconditioned reflexes. Thus some manifestations of the unrecognizable seem inborn. Such are grammatical structures which a child masters through imitation long before he is made aware of them at grammar lessons. The similarity of the subconscious and the inborn is reflected in the everyday metaphors such as "the class instinct" and "the voice of blood".

Another variety of the unrecognizable will be referred to, following Konstantin Stanislavsky and M. G. Yaroshevsky [4], as superconsciousness. Stanislavsky used this term in conjunction with super- and super-super-objective of the creative process. We have used it in our earlier papers [5].

The functioning of the super-consciousness which generates new information by recombining the traces of impressions of the outside world is not controlled by a conscious act of will. Consciousness receives only the results of this activity [6].

Superconsciousness covers the initial stages of any creative activity such as the generation of hypotheses, guesses, and inspiration. Subconsciousness protects consciousness from overworking; the unconsciousness of creative intuition is protection from premature interference by consciousness or from undue pressure of the experience. Without this protection, common sense, the obviousness of directly observed facts, and dogmatism of deeply rooted rules would

strangle the ugly ducklings of bold assumptions or incisive thinking before they turned into beautiful swans of discoveries and breakthroughs. This is the reason why discoursive thinking is entrusted with the essential function of problem statement to the cognitive mind and with secondary selection of hypotheses that are generated by superconsciousness, first by logical evaluation and then through experimental, industrial, and social practice.

The action of the superconsciousness and the consciousness in creative processes is comparable with the functions of variation and selection in the "creative activity of nature", notably in biological and cultural evolution. The similarity of the advent of new forms of life and the creative activity of an individual brain was noted, e.g., by K. A. Timiryazev in 1901, W. Russel in 1973, R. Dawkins in 1977, M. V. Volkenshtein in 1980. This list is far from being exhaustive. The authors disagree sharply on the way this "evolutionary approach" is implemented. Thus, Popper's proposal [7] that his mechanism of hypothesis should replace Pavlov's conditioned reflexes is quite unacceptable, especially so because Pavlov himself noted the similarity of the generalization stages to the development of scientific thinking "which, first, obtains a more constant and accurate link and then rejects spurious links" [8].

There is much more to superconsciousness than mere generation of a "mental mutation", or random recombination of the traces stored in memory. By some laws, unknown to us, superconsciousness performs primary selection of the recombinations and submits to consciousness only those that with some probability agree with the reality [9]. This makes all the difference between the "craziest ideas" of a scientist, on one hand, and the pathological fantasizing in mental patients and the phantasmagoria of dreams, on the other.

Today's neurophysiology knows numerous mechanisms that can close the temporal links in one's brain between the traces (engrams) of earlier impressions; the agreement or otherwise of these engrams with the reality is not verified until a later comparison with the reality. These mechanisms which have been discussed elsewhere [10] include A. A. Ukhtomsky's principle of the dominant. The superconsciousness (creative intuition) has been found to work for the satisfaction of the urge which is stably dominant in the subject's hierarchy of motivations.

In the same way that imitational behavior can address the subconsciousness without being monitored by rational thinking, children's games are major tools to train and expand the superconsciousness. Free of utilitary and socially prestigious (until a certain age) goals, the game has a purpose and a value of its own which facilitate the tackling of unselfish creative activities. It is motivated by cognition and the urge to acquire knowledge, habits, and skills which will not be needed until later in one's life. These two urges nurture the action of the child's superconsciousness and make every child a visionary, a pioneer, and a discoverer. As one grows older, the urge to know more has to compete with vital and social needs while the superconsciousness has to divert to serving a broad spectrum of most various motivations. It is not a mere coincidence that truly great minds maintain, as has been repeatedly noted since long ago, some childish trains.

E. L. Feinberg has thoroughly studied the difference between intuitive conjecture, or generation of hypotheses, and intuitive discovery of the truth which does not require formal logical proof [11] as in the case of a scientist who feels that enough experiments have been staged or a judge who finds that sufficient evidence of guilt (or innocence) has been submitted. Recall that a judge has to make his

decision in compliance with his "convictions", the amount of proof never being prescribed. The law incorporates an intuitive "spirit" as well as the discoursive "letter". We feel that the common denominator in the genesis of the two kinds of intuitions is the shortage of data, necessary and sufficient for a logically consistent behavior. In the case of conjecture these data have to be found in the course of verification. In the case of directly "seeing" the right solution this information is essentially unobtainable, for there is no way to decide how many experiments have to be staged or where the court should draw the line in examining the evidence.

The phenomenon of the latter kind of intuition is another argument in favor of the term "superconsciousness". Indeed, discoursive thinking supplies information for decision making, submits a set of formalizable proofs to the consciousness, but a final decision is made intuitively and cannot be formalized.

The recombinational activity of the superconsciousness is fueled by both the processed conscientious experience and the reserves of the subconsciousness. Nonetheless, it incorporates something undoubtedly "superior to" the consciousness proper. This something lies in the essentially new information which does not follow directly from earlier impressions. The force which triggers the activity of the superconsciousness and guides this activity is the dominating urge. Experiments show that when uncertain visual symbols are submitted to the subject, the number of associations with food grows as the subject becomes hungrier. This experiment illustrates the innate motivational constraints that are imposed on the subconsciousness. Intuition is not a caleidoscope or a random game; from the outset it is bounded by the kind of the dominating urge and the amount of accumulated knowledge. Without the broadest

possible knowledge of chemical elements no generation of ideas would culminate in the discovery of the periodic law.

While the positive function of the superconsciousness is in generating new knowledge, its negative function is in overcoming the existing generally accepted ways of thinking. The most illustrative example of this function is the sense of humor expressed as laughter. Laughter is spontaneous; there is no need to understand logically why something is funny. Laughter as a positive emotion results every time from the difference between the forecast and the currently available data, this data rejecting, or dashing the forecast. Such is the structure of a good party joke. Humor is motivated by the quest for cognition and the desire to save effort. The incisive thought solves a logical problem in an unexpected short-cut. Humor is the triumph of new knowledge over imperfect and cumbersome, obsolete standards. Marx said that in laughing mankind says farewell to its past. Additional motivations, such as biological or social, add tinges to humor and makes it good natured or malicious or conceited or clever or stupid or carefree, thus making it "the surest hallmark of one's soul" as Dostoevski said.

Because people comprehend their motives only partially, the apparent conflict of the objective determinism in human behavior and the subjectively sensed freedom of choice is resolved. Baruch Spinoza was shrewd enough to see that dialectics of behavior. According to him, people think themselves free for the sole reason that they are aware of their own acts but not of their causes. The actions of a particular man are determined by his hereditary traits and the environment, primarily social. Science does not know of any other factor. On the other hand, the entire ethics and above all the personal responsibility are based, according to Hegel, on the unconditional recognition of absolutely

free will. Abandonment of freedom of choice would be a catastrophe of any ethical system and morality.

The sense of freedom and the ensuring personal responsibility follow from comprehensive repetitive analysis of the consequences of one's actions, so that the final choice is more sound [12]. The actual motivational dominant which directs the action ("the behavior vector", in Ukhtomsky's works) is the integral of the prevailing urge which is stably dominant in the hierarchy of motivations in a specific personality (the life dominant or the super-super-objective, according to Stanislavsky) and the situational dominant. For instance, the actual danger to one's life triggers the situational dominant of self-preservation which may be in conflict with the life dominant, or the socially determined need to be consistent with certain ethical patterns. The consciousness, as a rule in conjunction with the subconsciousness, accesses from memory and "visualizes" the consequences of the subject's actions. Furthermore, the conflict of motivations involves the mechanisms of will, the need to overcome the obstruction on the way to the chief objective, this obstruction being the self-preservation instinct. Every urge generates its own emotions whose competition will be seen by the subject as the struggle of fear and the sense of duty, shame of being pusillanimous, etc. This struggle of motivations culminates either in escape or in a courageous stand.

In this example personal responsibility and personal freedom of choice jointly inhibit impulsive actions in response to the current situation, gain time for evaluating the possible consequences and thus strengthen the dominating need which is capable of countering the situationally dominant fear.

In effect, it is not consciousness by itself or will power by itself that dictates the action but rather their ability

to strengthen or weaken this or that competing urge. This strengthening is implemented through the mechanism of emotions which have been shown above to depend not only on the strength of the urge but also on the estimate of the probability that it will be satisfied [10]. The urge which has become dominant (the actual dominant) will then direct the action of the intuition (superconsciousness) in search of an optimal creative solution of the problem which would satisfy that dominating urge.

Careful analysis of the memoirs of the best Soviet Air Force pilots in World War II reveals that instantaneous decisions unexpected by the enemy were taken not in fear or in fury but in an emotionally beneficial state of striving to win the "game", even though one's own life was at stake. In other words, components of the ideal creative cognitive urge were involved.

When the prevalent urge (the life dominant) is so strong that the situational dominants are suppressed, it immediately mobilizes the reserves of the subconsciousness and uses the activities of the superconsciousness for its satisfaction. The motivations are practically not in conflict and the prevalent urge is directly transformed into an actual dominant. In the case of heroic self-sacrificing actions when they rush to help without thinking, people are driven either by the "biological" parent instinct or by altruistic urges of a more complex social origin.

The formation of an actual dominant may prove a difficult task when the prevalent and situational dominants are in conflict and of approximately equal strength. Such conflicts are described in many classical works of fiction. On the other hand, the absence of an actual dominant (as in the case of a pensioner or a retiree) creates a heavy stress for many. Equally sorry consequences result from lack of a life dominant, when the individual becomes a plaything

of situational dominants, as are misbehaving adolescents, alcoholics, and drug addicts. What is significant is that such an individual is not, as a rule, aware of the true cause of his defeated state and provides most various excuses for wasting his life.

We have compared above the interaction of the consciousness, and the superconsciousness with that of selection and unpredictable variability in biological evolution. What we have in mind is not an analogy but a universal principle of any development which manifests itself in the "nature's creation" (origination of new species), in the creative activity of an individual, and in the evolution of the culture. There is no question of "transferring" the biological laws to socially determined mentality or the history of human civilization. Science has repeatedly come across similar universal principles. Such are the regulatory functions of feedback which are at work in the blood pressure regulation (even in biochemical processes) and in industrial process control. No "transfer" occurs but the fact is that the rules of control theory are generally applicable.

The same is true of the dynamics of the origination of the new, be it in philogenesis or in the individual (scientific, technical, artistic) creative activity of man or in the history of culture. To become a reality, the new needs four components: (1) an evolving population, (2) unpredictable variability of the evolving material, (3) selection, and (4) fixation (through heredity in the broad sense of the word).

In human creative activity the corresponding four components are:

1) the subject's experience (what he learns both from his contemporaries and from the preceding generations);

2) the activity of superconsciousness (intuition), or such transformations and recombinations of the traces (engrams)

of earlier impressions whose consistence or inconsistence with the reality is not established until later;

3) the activity of consciousness which subjects the hypotheses (acting as "mental mutations") first to logical selection and then to experimental industrial or social testing;

4) fixation of selection results in the individual's memory and in the cultural heritage of human generations.

In the case of civilizations the entire culture experiences an evolution but the new element (an idea, discovery, invention, ethical rule, etc.) originates in an individual material organ, i.e., the brain of a creative individual, rather than in an abstract interpersonal or superpersonal space. Likewise, although in biological evolution the entity is a population, the selection operates through individuals. The unpredictability of a discovery and the protection of the "mental mutagenesis" and "mental recombinations" from the interference of the consciousness and will are a *sine qua non* of development, much in the same way that the mutations have to be unpredictable if the biological evolution is to proceed. Complete formalizability and arbitrariness of the original stages of creative work would make it impossible and spell the end of development of the civilization.

For illustration, let us assume that genetic engineering and a sophisticated education system have enabled society to foster "ideal people". They would be ideal, however, only in our today's, inevitably limited, view that history will make obsolete. "The ideally programmed" people might prove very vulnerable if the future makes demands that are now unforeseeable. Fortunately, in the psychophysiology of creative work we come across one of nature's prohibitions which can be overcome no more than the energy conservation laws and the complementarity prin-

ciple can. All the endeavors to formalize and program creative activities remind of "research" in perpetual motion.

The superconsciousness is nurtured on the memories of experience which is stored in the consciousness and partly recorded in the subconsciousness, and hence cannot generate a hypothesis which would be completely "independent" of that experience. No genius of the primitive society could arrive at the theory of relativity. The genius is on many occasions ahead of his time but only to a degree. In other words, mankind attacks only those problems which it is more or less ready to solve. This is another case of unpredictable non-randomness of "mental mutations". On the other hand, society evolves via the world-changing activities of specific personalities, through the activity of their superconsciousness where scientific and technological discoveries, new ethical rules, and concepts of works of art are generated. A purely individual breakthrough in technology grows into an industrial revolution which changes the production relations. Thus, the higher nervous activity of man centered on his vital ("biological"), social, and ideal (creative and cognitive) needs becomes, in the words of Vernadsky, a tremendous planetary and cosmic force among other natural forces [13].

Let us formulate several conclusions.

1. The higher nervous (mental) activity of man proceeds on three levels: the consciousness, the subconsciousness, and the superconsciousness.

The consciousness processes the transferable knowledge that can become the legacy of other members of society. Numerous studies of the functional asymmetry of the brain have revealed that the external stimuli or events in the internal life of the subject remain unrecognized unless the speech zones of the cortex are involved. In creative activities it is the consciousness that formulates the question

to be answered and submits it to the mind which explores the reality.

The subconsciousness digests whatever was or can be comprehended under certain conditions. These are habits which become automatic, built-in social rules, and motivational conflicts displeasing for the subject. The subconsciousness protects the consciousness from overwork and mental overstrain.

The activity of the superconsciousness (creative intuition) manifests itself as the initial stages of creative activities which are not monitored by the consciousness or will, so as to protect the nascent hypotheses ("mental mutations and recombinations") from the conservatism of the consciousness and from the undue pressure of earlier experience. The consciousness has to select these hypotheses by logical analysis and by practice in the broad sense. Neurophysiologically, the superconsciousness transforms and recombines the traces (engrams) in the subject's memory, and closes new temporal links whose consistency or otherwise with the reality will be tested later.

2. The superconsciousness operates so as to satisfy the dominating need which dictates the direction of the "mental mutagenesis". Consequently, the "mental mutations" are essentially unpredictable but not spurious. Another channeling factor is the subject's experience stored in his consciousness and subconsciousness.

3. The recognition of the fact that the subject is not fully aware of his motivations resolves the apparent conflict between the objective determinism of human behavior (which is dictated by one's hereditary characteristics, education, and social environment) and the subjective freedom of choice. This sense of freedom is a very valuable achievement which makes the subject feel personal responsibility for, and analyze and forecast the consequences of his actions.

The retrieval of relevant information from the depths of memory amplifies the urge which is stably dominating in the hierarchy of motives in the personality and so enables this urge to withstand the test of situational dominants, or urges which are brought to the surface by the current situations.

4. In human creative activities the interaction of the superconsciousness and the consciousness is the manifestation of the universal mechanism whereby the new is generated in the biological evolution and in cultural development. As an evolving population generates new traits through selection of individuals the culture inherits from earlier generations those ideas, discoveries, and social rules that originated in the minds of specific explorers and pioneers.

5. The conscious activity alone can account for neither the dialectics of the determinism and freedom of choice, nor the mechanisms of creative activities, nor the actual history of culture. Only the recognition of the importance of psychologically incomprehensible and the separation of sub- and super-consciousness will lead to sound answers to burning questions in the science of man.

References

1. Лурия А. Р. Высшие корковые функции человека. М.: Издательство МГУ, 1962.
2. Гершуни Г. В., Кожевников В. А., Марусева А. М., Чистович Л. А. Об особенностях образования временных связей на неощущаемые звуковые раздражения у человека. *Бюллетень экспериментальной биологии и медицины*. Т. 26, № 3, 1948.
3. Брагина Н. Н., Доброхотова Т. А. Функциональные ассиметрии человека. М.: Медицина, 1981. (О специализации и парной работе полушарий мозга человека).
4. Ярошевский М. Г. Категориальная регуляция научной деятельности. *Вопросы философии*, № 11, 1973.

5. Симонов П. В. Высшая нервная деятельность человека: мотивационно-эмоциональные аспекты. М.: Наука, 1975. Симонов П. В. Категории сознания, подсознания и сверх сознания в творческой системе С. К. Станиславского.— В кн.: Бессознательное. Тбилиси: Мецниереба, 1978, т. 2. Симонов П. В. Эмоциональный мозг. М.: Наука, 1981.
6. J. Hadamard. An Assay on the Psychology of Invention in the Mathematical Field. Princeton, 1945.
7. Popper K., Eccles G. The Self and its Brain. New York, 1977.
8. Павлов И. П. Двадцатилетний опыт объективного изучения высшей нервной деятельности (поведения) животных. М.: Наука, 1973.
9. Симонов П. В. Эмоциональное возбуждение и «психический мутагенез».— В кн.: Второй симпозиум по проблеме «Человек и машина»: Тез. докл. М.: Научн.-техн. общество радиотехники и электросвязи им. А. С. Попова, 1966.
10. Симонов П. В. Эмоциональный мозг. М.: Наука, 1981.
11. Файнберг Е. Л. Кибернетика, логика, искусство. М.: Радио и связь, 1981.
12. Симонов П. В. Детерминизм и свобода выбора.— В кн.: Методологические проблемы физиологии высшей нервной деятельности. М.: Наука, 1982.
13. Вернадский В. И. Биогеохимические очерки. М.; Л.: Издательство АН СССР, 1940.

The Principle of Active Operator in Engineering Psychology

B. F. LOMOV

The engineers do their best to ensure that the instruments show all the data necessary for efficient control of the machinery. The operator will not, however, perceive this data correctly unless the laws of perception, concentration, memory, thinking, and the dynamics of human psychological states are recognized in developing the instrumentation

because otherwise the control system is susceptible to human errors. The human factor should obviously be incorporated into the design from the earliest stages. This is what the engineering psychology*, which studies the data exchange between man and machine, is about.

Anthropocentric Approach to Analysis of the Man-Machine System

Once the man-machine system was viewed in the following general terms. All the changes in the process were picked up by sensors whose signals were fed into the instruments which were observed by man who decoded the instrumental readings and responded accordingly. The signal resulting from the operator's action was fed into the process and changed its state. The new state generated new signals, etc. In this picture man was regarded as a rather unsophisticated element whose activity could be described behavioristically in terms of stimulus and response. The goal was to make man "fit" the loop of the control system. The operator was described either as a frequency filter or as a linear low-frequency amplifier. Some researchers tried to determine his "input" or "output" characteristics, more specifically, their magnitudes which were assumed to be independent of the actual work.

That was the machinocentric approach in which simplification of labor was the chief way to make machinery and man compatible. Methodologically that approach followed the Taylor system which was embodied in the belt conveyor processes early in this century. The approach did yield

* Engineering psychology is an important part of ergonomics, which also includes physiology, anthropometry, and some other disciplines.

some useful findings in particular areas such as the optimal size and shape of the scale, most readable shapes of letters and numbers; generally, those results had a bearing on the specifics of perception rather than the entire totality of factors influencing control of actual machinery.

As engineering psychological research gained pace, the narrow scope of the machinocentric approach became more and more obvious. What worked in the experiment was not necessarily confirmed in practice. In determining man's "throughput", or rate of data processing, man was regarded as a communication channel. But man's throughput is influenced by his motivation, emotional state, stamina, skill and numerous other "variables". Man displays the entire variety of human characteristics even when acting as a system element. If so, studies of man as an operator should give way to studies of the operator as man.

This reasoning has resulted in reassessing the man-machine system. A new, anthropocentric approach was worked out in which the man-machine interaction was viewed as the relations between the subject and his tools. In this approach, which was adopted in the Soviet engineering psychology from the outset, the chief element in the description of the system was man's activity as the basic component of the control process whose structure and objectives dominated all other elements of the system.

In this anthropocentric approach the man-machine system is assumed to act in the following way. Man has to make the process change the state or to maintain the desired state of the process despite exogenous perturbations. The available data help man visualize the image of the desired state. In receiving the signals from the data representation system man estimates the current state of the process, compares it with the image, analyses the possible actions, makes a decision, and performs a control action which

changes the state of the process. The information on this change is communicated to the operator. He estimates the situation at hand to see whether the goal has been reached and either does or does not perform a new control action.

In this sequence man remains an element of the system but this element organizes the entire system and makes the system act towards the goal which he has set. It is man who sets the goal and particular subgoals, performs the control actions, and evaluates their results. The machinery of any kind remains man's tool.

For illustration let us take up the pilot-aircraft system which has been explored by the engineering psychology more than any other system. In this system all the disadvantages of disordered data exchange had been most obvious, which compelled the engineers to turn to psychologists for help in the early days of supersonic flight. The pilot controls a complex system, moves with it, and experiences the physical consequences of changing the environmental parameters. The pilot interacts with the aircraft directly through vestibular, muscular, and other sensations which may provide auxiliary and sometimes even basic data on the flight conditions.

However, there is more to the specific features of the system. The degree to which the data processing and control functions are automated may change significantly in flight; if the automatic units fail, the pilot has to take over immediately. For these reasons the pilot-aircraft system is an unusually convenient model for studying the effect of automation on the activity of the human operator in automatic and manually controlled flight, and the dependence of flight efficiency and reliability on this activity.

The most important finding was that because of automatic units the participation of man is reduced in the most detrimental way. In manual control the pilot pulls the

levers but also receives a continuous flux of muscular impulses which, together with the visual signals, inform him of the way the aircraft behaves and of the results of his actions. When automatic units take over, the pilot's motion analyzer remains inactive. What happens is sensory starvation of the complex neurodynamic system which compares, predicts, and generates corrective actions; the feedback mechanism ceases to be all-important and man is no longer prepared to perform effectively his basic function, which is to back up control in automatically controlled flight.

After a half hour in an automatically controlled flight it takes the pilot ten times longer to detect significant deflections in the instrumental readings than after a half hour in a manually controlled flight. This happens because the motion analyzer has been switched off.

In manually controlled flight the control is continuously dependent on data processing by the pilot. This process is an integral part of the sensomotoric actions which become unconsciously automatic with experience. In automatic control the monitoring of instrumental readings becomes a new activity which has to be controlled by an act of will through specifying a new objective. When decisions have to be made instantly this deautomation of automatic responses is fraught with danger.

Piloting has become so complicated that automatic units have become a necessity. At the landing phase the pilot used to monitor continuously five or six flight variables moving his eyes from one instrument to another as fast as 200 times a minute while at the same time performing numerous routine calculations. He has been relieved from this hard and error-prone work by integrated flight directors through which the airborne computer sends commands to him. Everything is okay as long as the automatic system

is faultless. But imagine that the computer has failed and the director readings are faulty and contradict the readings of conventional flight instruments which are nearby. The pilot, however, cannot tear his eyes off the director panel. He is fascinated by his automatic supervisor, fascinated because he has lost sight of his goal. In manual control he was to maintain the agreement of the actual parameters and the set points. Now his objective is to maintain the desired readings of the director. The image of the flight which used to control the pilot's actions has changed beyond recognition and he has ceased to be the active element of the system. This role has been taken over by the director signal.

The pilot ultimately understands that he has been misled. But precious seconds have been lost for correctly assessing the situation. The pilot has to exert enormous efforts to restore psychologically that degree of active participation which is essential for manual control to be efficient.

It is quite natural that control functions are taken over by automatic hardware during complex stages of the flight. But is the reduction of the pilot's participation inevitable? Could the shortage of information which is responsible for this reduction be compensated for? A fault in the system must by all means be signaled but the choice of this signal should be preceded by thorough psychological studies.

Two options of such emergency signaling were studied in a simulator. In one an instrument on a special panel lighted up to refer the pilot to a particular instrument which was to be used to control the flight manually. In the other the lights went on in the instruments by which the flight could be controlled in such emergency. The latter option proved more effective. The informational value of both options was the same but the time elapsed before the pilot started to act was different. An analysis of the pilot's

eye movements has revealed that in the former case he moves his eyes first to the director and only then to the manual control panel. While he does so, the manual control instrument (having a finite response time) is still silent. A delay prevents it from displaying data which would guide the pilot. Consequently, instead of waiting for that data to be displayed, the pilot, as if failing to believe his eyes, turns to the panel, looks at other instruments, and then tries to resume control, not purposefully but tentatively, as if testing the validity of the signal. If anything, at this stage the deflection from the right path only increases.

The situation is quite different when the failure signal is combined with useful data. The searching movements of the pilot's eyes are minimal and he makes just one third of the tentative movements of the former option. What is more, in the latter option the need in additional information is not so acute, the signal is comprehended faster and better, and the strain in transfer from monitoring to control is eased. The pilot does not perform erratic movements but lets the situation clear up. He does not make a decision before misalignment signals are displayed for him. Thus, the combination of two signals in one indicator improves the pilot's alertness and the reliability of his action. The degree of his participation is adequate for his function.

The pilot's involvement is equally useful in autopilot flight. Thanks to the automatic hardware the pilot is not so deeply immersed in tasks of manual control but nothing important escapes his attention. He may cease scanning the instrument panel for relatively long intervals but neither the piloting nor other tasks such as search for objects on the earth suffer. The pilot's preparedness to shift to manual control is not reduced because the structure of the data

exchange in the pilot-aircraft system is nearly the same as in manual control. The periodic correction of the autopilot facilitates maintaining the neurodynamic visual-proprioceptive links* that are essential for starting the control actions, and preserves that alertness of the organism which is necessary to participate in the process and which A. A Ukhtomsky so properly referred to as *operative inaction*.

This state has been studied in numerous experiments. During the entire "joint" flight the pilots have been found to maintain a high degree of "muscular vigilance". The motion analyzer was continuously prepared for action. The perception of the instrumental readings was stable: the sequence and frequency of eye movements from instrument to instrument at the sixtieth minute of the flight were exactly as at the tenth minute. The following experiment confirms that the eye movements are indicative of the general intensity of psychic processes, above all perception and attention. At the 30th minute the experimenters introduced failures into the speed indicator without informing the pilot. All pilots detected changes in instrumental readings within five seconds. When failures were introduced in fully automatic flight, they were not detected until after as much as 160 seconds.

The alertness of an individual who is a stand-by element in a man-machine system may be improved by proper training. If the operator does not have a clear idea of the operation of automatic hardware he may be either too cautious and try to manage without it even when it can obviously be useful or, be overconfident of its infallibility.

---

* Proprioceptors are end formations of sensitive nervous fibers in skeletal muscles, tendons, and joint bursa; they are stimulated in contraction, straining or extension of the muscles.

The inability to appreciate the potential of the hardware, especially in situations which have not been envisaged in the program, makes the operator unsure of himself, overly strained, and prematurely tired.

N. D. Zavalova and V. A. Ponomarenko, psychologists who had been studying the pilot-aircraft interaction for years, tried to improve the pilot's alertness in a "training" experiment. The formation of an integral director signal was explained to the pilot; the relative independence of the director index readings and the sensor readings was demonstrated; the attributes of computer or autopilot failures were studied. The pilots were asked to detect and recognize various failures of these units and, wherever possible, to continue using unfailed elements of the automatic hardware in control. This training dispelled the notion which was about to take root in the minds of some personnel that the hardware only simplified the work. This training also made the pilots confident that in emergency they could take over the control. Once they knew how the automatic control system operated, the pilots succeeded in differentiating various failures and, rather than disconnecting the hardware in response to any fault as they used to do before, tried to make use of the unfailed elements in the cases of partial failures. This training helped increase the accuracy of certain maneuvers with failed hardware by a factor of one and a half to three.

The Principle of Active Operator

Numerous experiments led Soviet engineering psychologists to a principle of active operator whereby, rather than becoming a passive attachment to the machine, man is kept active although his functions are partially transferred

to automatic hardware. This principle is a natural extension of the anthropocentric approach to the man-machine system which, in contrast to the machinocentric approach, is not designed to simplify work but to make the technology better adapted to man.

The wider the application of the principle, the better the system performance. No matter how psychologically effective the failure signaling is, the performance is not improved unless the operator knows the trends in the process behavior and is somewhat ahead of the events.

This principle and the anthropocentric approach in general will obviously triumph when every man-machine system is designed in the closest possible cooperation of the engineer and the psychologist. Today the psychologist on most occasions acts as an advisor in developing a new system or in modifying an old one. But even when the psychologist is a coauthor, his role boils down to optimizing the maintenance procedures. The original design is amended, sometimes very substantially, by engineers who know of the principles of engineering psychology, but this activity is only a step towards design because the machine remains the center of the design effort. The psychologist must design the activity of the man who will operate that machinery in the way that the engineer designs the machinery and its functioning. What is more, the machinery itself must be developed with an awareness of the design of this activity and of the conditions under which this activity is to be performed. There is no other way to obtain an optimal interaction of the operator and the machine and, consequently, to ensure the reliability and efficacy of the system.

Towards a Theory of the Operators Activity

Engineering psychology began with studying the "input" and "output" characteristics of the human operator, from analyzing mental functions, properties, and states which somehow or other manifest themselves in the operator's activity, and from solving particular problems and giving specific advice. The engineering psychology has grown to the development of the principles and methods of designing the activity of a human operator. These principles have not taken shape but we will describe, albeit briefly, the fundamentals of their development. These fundamentals are provided by the theory of the operator's activity which evolves from the experience of the engineering psychology and the concepts of general psychology, the labor psychology, physiology, control engineering, and some other disciplines. This theory is developed by using the methods of systems analysis.

Any activity is motivated by specific considerations and has to be goal-directed. The relation of the motivation to the goal is a kind of vector defining the direction and the intensity of the activity. The motivation represents both the individual's feelings about his activity and the needs of society; it has a direct impact on his state of mind and his ability to work. The combination of motivations dictates the period during which the individual gets accustomed to his activity, the stability during the stage which is referred to as "the final dash", and the nature of selectivity in perception, memory, and thinking. The individual regards the motivation as a force which acts on him personally and as a direct cause of his activity; the goal to him is a state or an event which is inexistent now but will be the culmin-

ation of his activity, in effect is an image in the broad sense of the word.

The laws and mechanisms whereby the image of the goal is formed are a central subject of research both in psychology and in neurophysiology. These sciences have for a long time been using notions such as anticipation, extrapolation, pattern and plan, anticipatory acceptor, model of the desired future, etc. The best of such terms is, in our opinion, Anokhin's "predicting reflection" which is generic for the above terms. In analyzing the operator's activity the engineering psychology heavily relies on the physiology of activity, a field to which P.K. Anokhin has greatly contributed. In 1935, long before the advent of control engineering, he discovered afferentation, a mechanism which compares the results of the action with the desired goal, and attributed to this mechanism a major role in the behavioral act. The principle of active operator and other concepts of the engineering psychology fit well Anokhin's theory of a functional system which is a closed-loop physiological entity where feedback information on the success of a particular adaptive action flows continuously. In studying the activity of a human operator this theory acts as a conceptual bridge between psychology and neurophysiology.

There are different forms of predicting reflection. The most important of them are forecasting (or anticipation, or extrapolation), which is most obvious when the operator has to continuously correct the process (as shown by V.M. Vodlozerov and myself in the case of an individual engaged in tracking activity), and goal formation. The achievement of a goal is thus a process rather than a single act. The goal is "decomposed" into a chain of partial goals. Each of them is achieved by performing a certain action. In some cases every subsequent action is prepared by a preceding one. In others, when the operator has to solve

several problems concurrently, a direct logical connection between the actions does not necessarily exist.

In short, different systems of actions may have different structures. In every case the operator has to keep in mind the image of the goal but in many man-machine systems he cannot do without various aids. The choice of the pictorial, symbolic, or command form of the aid is dictated by the specifics of the operator's activity.

The operator receives almost all current information from data display systems. The comprehension of this data proceeds in at least two stages: (1) perception of physical phenomena acting as data carriers such as combinations of light spots in the display or position of the indicator on the scale and (2) decoding of the signals and subsequent visualization of the process, or building of a conceptual model.

While the first stage has been fairly well-explored in psychology and psychophysiology, the second has not. The conceptual model includes both transformed signals perceived at a particular instant and the individual's experience, knowledge, and skills. This dynamic synthesis of traces of memory and perception becomes an image with all its inherent features. It is general, schematic, and panoramic. The empirical psychology used to regard images as "shadows of perception". This view has been disproved. In image formation accidental features are eliminated whereas general, most stable, features remain. On the other hand, man isolates those elements of the object or situation that he believes to be most informative. An image is not a detailed subjective picture of the reality; it is rather a scheme where a maximum of information is carried by a minimum of elements. Finally, a conceptual model contains an image of the entire situation, all the conditions and circumstances making the environment of the object or the process rather

than an image of an object or process. What is more, the entire panorama of simultaneously visualized interrelated elements is represented in the model as an entity.

What is a conceptual model in real life? For a pilot it is the "image of the flight". Some pilots who are aware of the value of a mental image (conceptual model) of a flight train themselves by performing a maneuver or recovering from a maneuver with their eyes closed and then check their action against the instrument readings. This kind of training makes the flight image stable, simplifies the piloting, and builds up the pilot's confidence.

An activity has been said to materialize in a sequence of actions subordinated to a common goal or interrelated in some other way. This interrelationship is impossible unless the individual has a plan of activities which, like the goal, is visualized in advance. The performance depends on the planning quality. Thus, in the most elementary case the beginner operators act "by reference points". The actions are performed in response to signals; if the signals are random and frequent, the activity is strained and erroneous. In such cases the operator has no clear-cut plan; rather, he is led by the events. The operation is somewhat better when the work follows a strict but unduly rigid plan. Everything is fine as long as nothing unusual happens, but emergencies make such plans totally ineffective. The best way to plan is to develop an overall strategy without unnecessary detail so as to enable the operator to change the nature and sequence of actions when the circumstances change.

When he sets a goal or a subgoal, builds a conceptual model or performs actions, the operator makes decisions. Decisions are made in looking for ways out of an uncertain situation and in an elementary sensory process of signal detection. Rather than by the sensitivity of the analyzers, the process is dictated by the criterion which the operator

chooses depending on the task, the evaluation of the task, and the skill.

To make a decision is to choose one of several options. The most complicated parts of this process are mental manipulation of the images and determination of the way to act. First the operator identifies the uncertain situation, then generates several options, then evaluates the options, and finally chooses one which, in his view, leads to the desired results. Depending on the relationship between the option generation and evaluation processes there are five types of decisions: impulsive (the option is taken without evaluation); risky (the option is evaluated only partially); balanced (the option generation and evaluation are well-balanced); cautious (the evaluation partly suppresses the generation); and inert (the generation is suppressed and so becomes ponderous and uncertain). The extreme types of decisions, impulsive and inert, are most ineffectual; the best are those where risk is balanced with caution, where a kind of "cautious daring" is shown.

There are numerous classifications of decisions in psychology: the one above is most suitable for the operator's activity. In addition to types, decisions are classified by the ways they are made. Thus, the analysis of the pilot's behavior when the autopilot has failed identifies four such ways: (1) once the signal (e.g., of the aircraft roll) arrives, the pilot takes the necessary action with a delay of three to five seconds; (2) on receiving the signal, the pilot examines the instrumental panel and takes the action after a delay totaling 20 seconds; (3) the pilot examines the panel and makes tentative pulls at the levers, the delay taking as long as 50 seconds; (4) the pilot acts by trial and error, performing tentative, often chaotic and erroneous actions increasing the delay to 180 seconds.

In the first case the pilot makes a decision instantly, the

process being purely mental. In the second case the process is also mental but the pilot needs additional data to generate and evaluate the options. In the third and fourth cases the options are checked by trials as well as mentally; even the option generation needs support from motoric action.

The choice of the way in which the decisions are made depends on the skill and the conceptual model. The better the situation modeling, the faster and the more effective the decision. This signifies that the techniques of submitting the data to the operator should be developed so as to allow for decision making as well as perception. On one hand, the better the process and the environment are represented, the more probable is a right and timely decision. On the other hand, the amount of data may prove unwieldy. The designers must strike a balance between the two extremes.

Both theoretically and practically this is quite feasible. In some cases the operator is aided by computers which advise him on determining the sequences and amounts of the data. There are also special-purpose units which tell the operator where to look for data needed to make a decision in emergency.

Once a decision is made, the operator acts. The actions have of course been classified too, but we will only emphasize that each moment the action should adequately match the object, tools, and conditions of work because the data on them are contained in human mind and the emerging reflection is the controller of action. This controller may act at the level of senses and perceptions, at the level of images, or at the level of speech and thinking processes which possess the highest degree of abstraction and generalization. In actual work these three levels interact; only their priorities change to suit the object, tools, and conditions of work.

In the operator's mind the data on the current state of the object and on the results of his actions are reflected as

a subjective image. This image is operational in that it is intended for correct and fast performance of jobs. It is an ideal specialized reflection of the object, a reflection which forms as the operator acts. It is subordinated to the operator's goal; in psychology it is referred to as an operational image.

The operational image is an extension of the goal image and the conceptual model. It overcomes their "misalignment". The operational image changes with every action conducive to the goal. The feedback signals on the results of actions update the image. Shaped as the data are acquired and processed, the operational image, being a sort of mobile conceptual model during the attainment of the goal, shapes, in its turn, the course of the process and the way it runs.

The time and accuracy of performing the actions depend on the professional experience. The actions that have been brought to high perfection, performed easily and fast, with the best result and with the least effort, are skills, which are the most valuable aids and "automatic" components of conscious activity.

Motoric habits are best explored in psychology. They are controlled by motoric structures which integrate individual motions into one whole. Skilled personnel perform a sequence of particular motions as one complex motion, accurately and economically: unless one is familiar with the synthesis of this sequence in the course of training, one cannot imagine the welter of adaptive motions which accompany the essential movements and disappear gradually as the skill takes root.

Another major feature of motoric skills is the increasing ability to choose from the flow of signals those which have to do with a given motoric task. In addition to a motoric structure, a sensory structure, or, to be more precise, a senso-motoric structure develops which acts as the mechan-

ism governing any skill. The operation of the analyzer is resequenced. First the most important function in the regulation of motions is performed by visual signals; then, as the training proceeds, tactile and proprioceptive signals, or those from the muscles, tendons, and the vestibular apparatus, come to the fore. The feedback function is taken over by the motion analyzer. The reason is simple: the length of the "control" cycle in such an "inner" loop is half or one third that of the "outer" cycle.

Once the inner loop sets in, the operator concentrates more on the result of the entire action rather than on his own motions. The priorities of the control levels also change. The motions are controlled by sensory-perceptive, rather than by speech and thinking, processes; the thinking is engaged in overall monitoring and tasks more appropriate for it. The skill may seem to be uncontrolled by the mind.

Psychologists have for a long time been studying the formation of skills. They want to know more about the interaction of old and new skills and to understand which elements of the old skills are helpful and which are not in acquiring new skills. The results of studies are summarized in advice to be used in the training of operators.

The theory of operator's activity has not yet taken shape but its general outline is visible as is the conceptual framework which, by analogy with the ideas of Anokhin, Bernstein, and their followers, may be referred to as the psychology of activity. Such a science is the engineering psychology of today which addresses itself to practice, to technological progress, and to its protagonist, the working man.

The Organism and Age

Ageing and Old Age

V. I. KLIMOVA

The very fact that some people remain active in old age confirms that ageing can be biologically optimized and extension of life is a realistic possibility.

The longest life on record was lived by Thomas Parr who was believed to be 152 years and more than nine months when he died in 1635. The autopsy performed by William Harvey, the great British surgeon, confirmed that age.

More than three centuries later this record was broken by Shirali Fizoli ogly Mislimov, an Azerbaijan peasant, who was reportedly born in 1805 and died in 1973 at the age of 167 years.

When Matayo Achoungo of Kenya died in December 1976 at the age of 132 all Kenyan newspapers published obituaries and the funeral, attended by scores of his children, 125 grandchildren, and thousands of mourners, was televized live.

In 1980 Zanati Mishaal, an Egyptian fellah, celebrated the 105th anniversary of his wedding. He was 130 then and the oldest citizen of his country. His youngest son was 72. Zanati Mishaal had been ill just once in his life, when he was 120.

There are also some less verifiable reports of long life.

Jean Tairele was born in Dijon, France, in 1684. He enlisted in the army at the age of sixteen. He was given captaincy by Louis XVI in 1777 and dismissed by Napoleon after more than a century of service at the age of 118 years. Tairele died in 1827 when he was 143.

Zoltan Petrage, a Hungarian, reportedly died when he was 186; Zaro Aga, a Turk, when he was 156; Medjid Agaev of this country lived more than 140 years. Mahmed Ayubu of Iran said he was born in 1790. In 1970 he was 180; he had married the last time 20 years before. He had 170 grandchildren. This longevity is so unusual, even sensational, that we understand why gerontologists are cautious in evaluating such reports. The scientists of the Gerontology Institute of the Academy of Medical Sciences of the USSR, Kiev, who compared the possible life spans of various animals and physiological and functional parameters agreed that the maximal human life span is 115-120 years.

The age of the comparatively large group of people who are said to be around 100 is not therefore biologically in doubt.

According to the 1970 census, in the USSR 2,998 men and 11,087 women were 100-104, 110 men and 229 women were 120 and more, and the long-livers totaled 19,304. Only one person in 10,000 has a chance to live to that age. This is the so-called species age which is dictated by the genetic program.

Indeed, some species live for hours, some for scores of years, and some for centuries. Some representatives of every species die very early and some very late for their species.

The reason for early death is easy to find. Why some people manage to live for an unusually long time remains a mystery. The natural life span of man has not been determined, either.

Studies of long-livers may help understand this mystery.

Who are the long-livers? Are they just lucky or specifically talented people? Or are they record breakers? All of them have undoubtedly succeeded in optimal "investment" of their health; their organisms perform self-regulation with utmost precision on every level.

Similarity of Variety

As might be expected, the long-livers are very different. They have led different kinds of life, have different habits, affections, and inclinations. Scientists, however, want to know more about the reasons behind their long life.

Consequently, it is very important to know where the very old live, what their diet is, what their life style is, whether they are often sick, and what their inherited features are.

The geography of long-livers is most varied. The very old are Daghestanians and Abkhazians, Latvians and Evenks; they live in the middle of Soviet Europe, in the Western Siberia, and in Central Asia. They live in Iran, Turkey, India, Japan, Latin America, and Africa.

There is no uniformity in their diet. Some of them, e.g., Mme Simone, 105, a French writer, say they have never observed any special diet. The national cuisine may give a better insight than the testimony of individuals. The age-old Abkhazian food includes maize gruel, cheese (chiefly of the goat milk), much vegetables and fruits but nearly no animal fats, little fish or meat, a limited amount of salt and sugar. On the other hand, the Azerbaidjanians consume much meat and fat. The diet of the Evenks is quite different. It includes venison, animal fat, fish, a little of vegetables, and wild berries.

The diet of the old in Moscow and Leningrad is in most cases conventional. The old in the Vilcabamba valley in Ecuador consume as little as 1,200 calories every day. Their diet includes about 40 g of protein, 12 to 20 g of fats, and 200 to 260 g of carbohydrates. The proteins and fats are chiefly vegetative, the amount of animal proteins never exceeding 10 g a day.

Cornaro, the Italian who advocated the view that the way to long life is through eating little food and reducing the metabolism to a minimum, ate as little as 300 g of hard food and drank 400 g of liquid a day. In 1558 he published a book "Reasoning on temperate life". He lived more than 100 years and was always in good mood.

True, very old invariably cut the consumption of meat, sugar, and piquant and fat foodstuffs while increasing the consumption of sour milk, vegetables, and fruits. But this diet is also characteristic of the middle aged. True, every long-liver has his or her preferences but their diet is chiefly conventional. Among the very old are peasants, workers, scientists, journalists, and writers. Consequently, they lead different kinds of life.

Sometimes the answers to questions about the secrets of the life style leading to a very old age are unambiguous. Another centenarian, George Klobuscher of USA, attributes his old age to cycling which he has been practicing for 83 years every day in any weather.

On most occasions the answer is not so certain.

Philip Wright Whitcomb, who worked for 64 years as a journalist, entered Kansas University when he was well-advanced in years and graduated from it at the age of 89. He wrote on many subjects ranging from tourism to economic reforms. His life was by no means quiet. He believes that he owes his good health and an alert mind to a reasonable view of himself. Since he was 12 he went in for various sports and scored a measure of success in football, rugby, basketball, running, rowing, and boxing. He never ceased pursuing his hobby which is studying various philosophical schools. What is very important, he never drank liquors or smoked, and avoided medical drugs.

History, if nothing else, changed much in the life of the oldest inhabitant of this planet, Shirali Mislimov. Hard,

poorly rewarded work for a landlord, injustices, continuous threat of undeserved punishment changed to the work of a shepherd, which requires patience and stamina and is very important for his collective farm. A big family made it necessary for him to work hard and be patient and just. In response to questions he said that he had never been in a hurry, and never hurried to live. He worked with his hands for almost 150 years. He said that people should work and eat what is necessary for health.

Even when very old he went for long strolls. He did not eat beef or mutton, liked chicken soup, cheese, and sour milk.

In response to a question, what kind of life had helped him to keep healthy, alert, and capable of useful work Academician A.A. Mikhailov, the director of Pulkovo observatory (he died in 1983 when he was 90) said, "I did nothing for this but then I did nothing harmful to my health... I simply led a life which helped to achieve an active old age. I never smoked or drank; I slept at least eight hours every day... I think that my life in the countryside for the last 26 years was also helpful. My old age seems to result from many favorable circumstances which outweighed many negative effects".

The negative effects were the hereditary features, of which gerontologists always take note. His mother died of tuberculosis at the age of 29 and his father, of angina pectoris at the age of 65. In his youth the scientist suffered from bronchitis.

Some of the long livers come from families in which nobody reached an old age but most of them have children who are also very old. Thus, Miguel Carpio, the oldest inhabitant of the Vilcabamba valley, was 123 and his daughter was 98. Micaela Quezada was over 100 when her elder sister died at the age of 107 and her 12 brothers were around 90 years old.

With all the differences between the lives they lead the long-livers as a rule avoid liquors, do not smoke, eat with moderation, and appreciate physical efforts, good sleep, and fresh air.

The characteristic features of the long-livers are better revealed by studies of very old people in various ethnic groups.

Very old are to be found everywhere but in some places their percentage is higher. Sizable numbers of them are concentrated only in several places.

Long-livers are numerous in some valleys in the Andes at an altitude of 1,500 m. In Vilcabamba nine out of the 819 inhabitants were over 100 in 1971. There are many very old people among the ethnic Scots and Irish in Kentucky, USA. They are numerous in the Hunza mountains in Pakistan. Their percentage is very high in the Caucasus. According to the 1970 census, with a population amounting to just seven per cent of the USSR's total, the Caucasus accounted for 16 per cent of long livers and 35 per cent of all centenarians.

In the USSR the percentage of very old is also high in the Evenkian National Area, in some parts of Tajikistan, and in the Baltic region.

Studies of groups of long-livers are a logical extension of studies of individuals; indeed, the phenomenon of an unusual old age cannot be explained even when the numerous functional, energetic, and data exchange interaction in an individual organism have been unraveled.

Gerontologists, sociologists, and scientists from many other fields have combined their efforts in a research project "Comprehensive biological, anthropological and socioethnographic studies of the peoples and ethnic groups with a higher than normal percentage of long-lived persons" of the Ethnography Institute of the USSR Academy of Sciences

and the New York Research Institute for the Study of Man [1].

The very existence of distinct "zones of exceptional old age" suggested the need to recognize the ecological dimension; this recognition culminated in the ecological hypothesis which emphasizes that the unusually favorable ecological conditions are akin to the ecological conditions favoring the development of the Homo sapiens species. These conditions are the climate, the chemical composition of the soil and water, the altitude, the vegetation, and the animal world, in effect, the entire environment to which man has adapted and which has shaped some of his physiological qualities.

The ecological theory has very much in common with the genetic theory which emphasizes the hereditary "ability" to withstand unfavorable conditions for a long time and to adapt. True, the "gene of longevity" has not been discovered but some hereditary factors enhanced the resistivity and immunity to diseases.

Some biological differences between the long-livers and their relatives, on one hand, and people who live nearby but do not reach a very old age, on the other, have been determined. Anthropologically, the long-livers are usually short and lean. Their physiology is somewhat different as is, according to the EEGs, the neuro-reflectory activity.

The interdisciplinary studies of the phenomenon also revealed the importance of psychological factors and culminated in two more hypothesis, personal psychological and socio-psychological. The former attributes longevity to the specifics of the personal psychology. The people who are likely to live to a very old age are optimistic, easily adaptable to changes in their life, and stable under stresses. This hypothesis is usually combined with the genetic hypothesis. Indeed, since some psychodynamic traits can be inherited, so can be the psychological features. The latter hypothesis

assumes that longevity is favored by a socio-psychological environment which assuages the difficulties, conflicts and stresses. Thus, the habits of mutual help and the traditional etiquette make the physical and moral strain easier. Some features of everyday life and the close links between the old and the people around them favor the reaching of an old age.

The amount of attention the scientists give to longevity is quite understandable as is the importance of their findings in the context of this book. It is very important to know of any effect on the operation of a living self-regulating complex system of the human organism, be this effect biological, ecological, psychological or social. This knowledge may help hold back the genetic program of ageing, "disturb" that program and thus use the reserves of the organism in an optimal way and give more years to life and more life to years.

Towards an Active Old Age

The stage of oldness is as natural in human life as any other. But does this stage necessarily arrive "in proper time"?

The work for extending the healthy and active period in human life proceeds along two directions: studies of the secrets behind the old age and search for the physiological mechanisms of ageing.

The researchers try to follow this process on all levels, from the molecular to that of the entire organism. Ageing is seen to be somewhat synonymous with destruction. The ageing changes the action of the cells, organs and systems of the entire organism. It disturbs the physiological functions and destabilizes the optimal control and regulation function, i.e., reduces the adaptability. In what way does

the ageing occur? This article will summarize only the genetic theory which is now widely recognized as the best possible embodiment of particular interpretations, experimental evidence, and diverse reported facts.

The genetic theory presumes that the ageing process is genetically programmed and is influenced by the rhythmical processes in the organism, by the operation of the biological clock deep inside the brain, in the hypothalamus [2].

One variety of the genetic theory assumes that the organism ages not because the clock stops ticking but owing to genetic damages to the program which accumulate as the system cannot cope with them in time.

The adaptation theory, which is supported by ample experimental evidence and sound theoretical reasoning, views the ageing as a multistep process in which the adaptability deteriorates [3].

The ageing is believed to result from a reduction in the potential of the self-regulating mechanism which follows primary changes in the regulation of the genetic machinery.

However, the ageing is an internally conflicting process in that degradation and the disturbances of metabolism and functions go hand-in-hand with a mobilization of all important adjustment mechanisms.

The organism does not age all at once. Some changes occur earlier and some later; their intensities are different and so the organism is capable of getting prepared for self-defense and creating new adaptation mechanisms. For this reason ageing is not only a fading of the organism but also a new way to adapt to the environment and to maintain stability.

Some changes are primary and some are secondary. The most important changes occur in the nervous activity and in the neurohormonal regulation. The perfection of adapting mechanisms depends on the central nervous system. The

neurohormonal mechanisms influence the operation of the genetic machinery; in old age the sequence in the operation of genes is disturbed and this results in a disturbance in biosynthesis. The content of some proteins decreases and that of some others increases, so that the functioning of the cells, tissues and organs is destabilized.

The adaptation theory does not provide a full explanation of ageing but succeeds in demonstrating how it proceeds; what is more, it leads to useful conclusions. To change the ageing of a living organism is very difficult now but once the compensating mechanisms of the organism are described, the "program of ageing" itself can be turned against ageing. The emerging adaptability of the organism to existence in a new condition can be amplified in order to increase the life span. Moreover, there is abundant evidence that the cells carry substances which "repair" the genetic machinery by "removing" the withered and error-distorted parts and replacing them with renewed ones. Still another technique is to "revitalize" the "vulnerable" parts in the genetic machinery chemically.

This theory also accounts for the differences between age-induced changes in the organisms of different individuals of the same age. Many people are said to look younger or older than their age. These differences reflect the biological age, or the status of age-induced changes and health, which may deviate from the calendar age.

The rates of ageing depend on the adaptability of the individual. Slow rates, largely attributable to well-developed adaptability, are characteristic of normal physiological ageing. A fast rate, which reflects poor operation of the adaptive mechanisms, culminates in early oldness.

Consequently, the interaction between ageing and the compensating adaptive mechanisms dictates the biological age and the life span. It is the biological rather than the

calendar age that is the reflection of an individual's health.

There is still another kind of age, psychological. The personal view of one's own age also makes an impact on one's health because it dictates the individual's view of himself and his mood. A 50- or 60-year-old who, most often on the strength of tradition, thinks of himself as hopelessly old and starts to live accordingly would hardly extend his life. A reduced period of active life spells a shorter life.

The biological approach alone to extending one's life and the active period of it thus seems to be insufficient. Since man is a social being, the ageing depends on the emotional psychological factors and on the social conditions as well as on the biological mechanisms.

The good old common sense has long formulated proverbs to the effect that one dies as he lived and the lazy do not live long. The individual's health, active old age, and life span largely depend on the social factors such as the life style and work. The inseparable unity of the biological potential and social factors is seen in the original notion of the life span. There is no such thing as "purely biological" or "genetically permissible" length of an individual's life. Once a person is born, the biological factors are continuously modified, and to a significant extent, by the conditions of life, the environment, and many unpredictable events. The still undetermined life span of man as a species probably is unlikely to have changed since the stone age and the medieval time to our times, but the average life span has grown from 19 to 20-30 and to 73 years, respectively, thanks to the improvement in the living conditions, the triumph over numerous diseases, and reduction of the infant mortality.

For this reason the ageing is not only biological but also social phenomenon. In a normal case the social ageing results from gradual natural exhaustion of the organism's reserves;

in pathological cases some social factors have accelerated the ageing.

To recapitulate, it is only in combining different approaches to extending human life that tangible results will be obtained. Man's life is longer when he uses his biological reserves sparingly and effectively and minimizes the negative and undesirable factors which reduce the life of man as a social being.

References

1. Феномен долгожительства. М.: Наука, 1982.
2. Дильман В. М. Большие биологические части. М.: Знание, 1982.
3. Фролькис В. В. Регулирование, приспособление, старение. Л.: Наука, 1970.

Extension of Human Life: The Biological Dimension and Experimentation

V. V. FROLKIS and Kh. K. MURADYAN

The tactics of extending the human life is full utilization of the natural human longevity and the strategic goal is making the natural life span longer [1]. The dramatic increase in the average life expectancy over the latest decades is chiefly attributable to the reduction of the infant mortality and to the successes in combatting infectional diseases. Still, the forecasts of nearly complete triumph

over ageing by the beginning or middle of the 21st century seem overoptimistic.

A large team of Soviet gerontologists have also issued a forecast of future successes in this field. Most of them, 65 per cent, believe that no later than by 2010 the average longevity will approach the ceiling which is the life span of an individual as a representative of the Homo sapiens species. According to 30 per cent, the longevity of individuals will extend beyond that limit in the second quarter of the 21st century, although 58 per cent doubt this. These, generally optimistic, forecasts assume that the findings of today's gerontology will be put to the most effective use.

Some believe that life cannot be extended unless the ageing mechanisms are unraveled and brought under control. This view is reasonable, although even to-date we know quite a lot. Some of these mechanisms which can be influenced so as to achieve both the tactical and strategic goals have been explored. Furthermore, on numerous occasions in the history of science, especially of biology and medicine, important phenomena were indeed brought under control before the mechanisms behind them had been unraveled. Finally, experimental studies of ways to extend life are essential for understanding the mechanisms of ageing and only experimental modeling can provide sound criteria for evaluating any theory of ageing.

One of such theories is the adaptation theory which incorporates the most important achievements of cybernetics. As the age advances, the changes which occur in various parts of the organism may in some cases compensate one another. The ageing proceeds along with *vitauct* (from Latin *vita*, life, and *aucto*, increase), a process which has been explored in the Gerontology Institute of the USSR Academy of Medical Sciences and which influences the activity of all levels, from the molecular and cellular to

that of the entire organism. The genotypical effects of vitauct are inherited and phenotypical effects are caused by self-regulation mechanisms.

The primary ageing mechanisms are believed by the advocates of this theory to act through regulation of the genome, i.e., not through changes in the DNA information on the structure of proteins but through changes in the mechanisms which control and execute the DNA information, or gene expression.

Within one century since the first scientifically sound attempts to extend life abundant data on the effect of various factors have been reported. For the purposes of this discussion they could be classified into physical, chemical, and biological. This classification is largely conventional because the "force of application" of many factors of different kinds and the specific mechanism of their life-extending action may prove more significant than different factors of the same kind.

Let us take up the effect of biological factors, even though other life-extending factors exist. Many authors believe that ageing-retarding factors may include electrical and magnetic fields, ions of various metals, chelating agents, lathyrogenes, stabilizers of lysosomal membranes, etc. [2].

The existence of organisms which live for centuries is ample proof of the immense potential of biological factors. Today we know too little of these factors to make full use of them; in experiments the resultant prolongation of life rarely exceeds 50 per cent.

Calories- and Protein-Deficient Diets

Since a lean diet had been found to increase noticeably the life expectancy of rats, diets different in the content, nutritional value, and frequency of meals became a widely used

subject of research in attempts to model ways to extend the life of warm-blooded animals. Despite the wide variety of conditions, in most cases a certain shortage of food resulted in increasing the longevity of experimental animals.

What is more, there is a direct relationship between the degree to which the amount of food is cut and the longevity. Thus, in rats a reduction of the daily diet by one kcal increased their life span by about four days. This extension was found to be attributable to a reduction in feeding at later stages of life, rather than to better keeping or to reduced mortality at early stages of life (it was higher for rats whose diet was cut than in control animals).

Calories-deficient feeding is most effective if started in early ontogeny periods. Once the mature stage has been reached, the food reduction is less effective and in some cases even decreases the longevity. Only gradual reduction results in some longevity increase for mature animals.

Another interesting finding is that the life expectancy is inversely dependent on the consumed amount only during the first 200 days in the lives of the animals. As they grew older, the correlation became less noticeable and from the age of 400 days the amounts of consumed food did not make any significant impact on the longevity. On the other hand, alternation of no-food days with days of unlimited feeding unexpectedly increased the average longevity of rats by nearly 80 per cent. The most general explanation is that limited feeding reduces the metabolic rate, which reduces the damaging effects [3].

The reader may recall that a negative correlation between the life span, characteristic of the mammals, and the metabolic rate was demonstrated by Rubner early in this century. The life-extending effect of calories-deficient diet is also believed to result in hormonal changes similar to those in light stress and activating the vitauct processes [4].

Another interesting fact is that the same effect is obtained by using a protein-deficient diet containing a normal amount of calories. What is more, reduction of the protein in the diet or of some essential aminoacids such as tryptophane, has been found very effective.

The rate of RNA and protein synthesis was found to drop and the lifetimes of these macromolecules was observed to increase in cells of most various types in response to shortage of aminoacids or energy. A probable explanation is that the rate of macromolecule degradation and synthesis falls and the cell starts using the genetic information more sparingly; the damage of DNA reduces and the longevity of an individual cell and the entire organism increases.

The life of starving animals can be extended by reducing the body temperature by two or three degrees. Starvation may be viewed as a good physiological way to reduce the body temperature so as to slow down the metabolic processes. Indeed, neither the calories-deficient diet nor the protein-deficient diet increase the longevity of many warm-blooded species whereas a temperature reduction has a pronounced life-extending effect.

Whatever the exact mechanisms behind it, the effect of starvation seems to work in humans as well as in laboratory animals. This view is supported by the experiments started in the Gerontology Institute. In aged people whose food has been short on calories for a long time the pathological changes in the cardiovascular system and in the lipid (fat) exchange are less pronounced.

Enterosorption and Antioxidants

Since the time of Elie Metchnikoff one school of thought relates the ageing to accumulation of damaging factors such as toxins. Nowadays this factor is seen as just one of many

processes leading to ageing. The increased sensitivity of tissues to these factors in the old age is at least as important as the possible increase in the concentration of toxins.

After this was understood, we developed enterosorption, an essentially new way to increase longevity. The human stomach produces eight to nine liters of gastric juice much of which is not used in digestion and is sucked back into blood. By adding sorbents which bind certain molecules the toxic agents are removed from the organism. In our experiments with rats enterosorption increased the life span by 30 to 40 per cent through maintaining the optimal rate of protein synthesis, slowing down the metabolic and structural disorders, blocking changes in the lipid metabolism, and delaying significant pathological changes. In livers of the animals the content of the R-450 cytochrome, an enzyme whose amount is usually well-correlated with the content of toxic agents in the organism, was found to fall.

One advantage of enterosorption is that, unlike most other life-extending techniques, it is most effective at late stages of the ontogeny when intoxication poses a real threat to life because of lower resistivity. This line of research is in its infancy and so the possible range of its protective action cannot be fully appreciated. When more effective and highly specific sorbents are available, enterosorption will hopefully become one of the most reliable and accessible methods of retarding the advent of the old age and extending human life.

The sorption methods extend life mostly by increasing the protective potential of specific organs at the cellular level, the use of antioxidants, or substances which react with and "quench" free radicals is another effective approach to life extension. The free radicals are known to be very reactive thanks to the presence of an unpaired electron,

and capable of damaging functionally important macromolecules such as nucleic acids and proteins.

Studies of the effect of antioxidants on the life span and the rate of age-induced changes in various metabolic characteristics have become a major line of gerontologic research. A significant contribution was made by D. Harman, an American researcher, and N.M. Emanuel, full member of the USSR Academy of Sciences, and other authors who found that in some cases the antioxidants increase the life span of animals by 40 to 50 per cent.

Similar studies were carried out in the Gerontology Institute. Dextramine was found to be an effective antioxidant. It was important to determine the "price" of extending life, or what changes occurred in the functional parameters of the organism. The age-induced changes in the motoric activities, behavioral responses, and the basal and lipid metabolisms occurred eight to nine months later than in control rats.

In trying to unravel the possible mechanisms of the life-extending action of anti-oxidants we found that they significantly changed the concentration of the pituitary, adrenal gland, and thyroid hormones which are known to have a significant impact on the ageing rate and the life span. In other words, the antioxidants probably reduce the amount of free radicals through changes in the hormonal content rather than directly. Other authors have also suggested the existence of such a mechanism.

Physical Activity

The effect of physical exercises on the life span proved very difficult to assess.

The oxygen consumption of insect in flight is 40 to 60-fold

that at rest. This might be expected to reduce the life span considerably. Indeed, when they are placed in a glass with a maze of partitions, flies live two to three times longer than usual. On the other hand, the life of very active mutants is noticeably shorter under these conditions. No clear inverse dependence of these variables was observed, however, in the work of several experimenters with seven strains of drosophilae.

Only individually optimal amounts of exercises may effectively stimulate the restoration processes. In experiments the life is shortened significantly by both hypokinesis and physical overstrain while reasonable physical activity such as voluntary or enforced walking or running increased the life span of experimental rats. In some experiments this effect is more pronounced in males and in other experiments, in females. The results also varied with the age. In experiments with 120-, 300-, 450-, and 600-days-old rats who were made to run the exercise increased the life span of animals younger than 450 days and reduced it in older animals.

These findings suggest that there is an "age threshold" above which physical exercises make a negative impact on the organism. This assertion was, however, criticized because the same enforced exercise may prove an unbearable strain in unfit and old animals.

Since obesity reduces the life expectancy and trained animals have a lower weight and store less fat, the life-extending effect could be naturally attributed to reduction of obesity in experimental animals. Besides, vigorous activity may retard the development of numerous pathological processes, notably in the cardiovascular system. Optimal exercise increases the stability to shortage of oxygen which is the cause of numerous pathologies.

I.A. Arshavsky, who compared numerous physiological

and morphological variables in closely related species (rabbit—hare, cow—horse, rat—squirrel) which differ in the amount of physical exercises and longevity, believes that an increased amount of physical efforts, especially the dynamic component of the muscular efforts, can significantly increase the longevity. His experiments have demonstrated that the optimal exercise reduces, not enhances, the basal metabolism by 40 to 60 per cent and increases the content of adenosine triphosphate (ATP) and protein, the membraneous potential, and some other important indicators.

Hormones

Gerontology owes the first wave of loud appreciation of gerontological experiments and subsequent bitter disappointment to attempts to use hormones in slowing down the ageing. The failure of rejuvenation by hormones in 1920s brought about a standstill in this kind of research which did not resume on any significant scale until 1950s and '60s.

The injection of testosterone was found to reduce somewhat the life span of castrated male and female mammals while estradiol increases it, but only for males. Castration itself increased the longevity of males and had no significant impact on that of females. When males and females were kept together their longevity increased by almost a quarter over that in separate keeping.

The thyroid hormones are unambiguously known to reduce the longevity. If thyroxine is injected for a long time, the mortality noticeably increases but falls to the normal value once the injections are discontinued. The calories-deficient diet, which increases the life span, inhibits thyroid secretion.

In rats which were kept at low temperatures (this regimen increased the rat mortality) the secretion of these hormones was found to increase.

Some researchers believe that reduced impact of tropic pituitary hormones may increase the longevity. This effect was indeed confirmed in refined experiments with animals whose pituitary was removed.

The life span is increased by using corticoids, in particular prednisolone, as demonstrated in extensive experiments with mice. Neurohormonal shifts are known to dictate the mechanisms of responses to stresses. H. Selye was the first to suggest that ageing results from repeated stresses. The actual picture is, however, much more complicated. Strong, especially repeated, stressors can indeed significantly shorten the life but regular mild stressors may increase it maintaining the tonus through neurohormonal regulation. This view is confirmed by alternating-starvation experiments and by studies of the direct impact of "soft stresses" on the life duration. In these experiments 600-days-old rats lived up to 1,110 days while control animals, only 938.

The growth hormone has been found to have no significant effect on the ageing processes.

Noticeable changes are known to occur in both the feedforward and the feedback loops of neurohormonal regulation. In particular, "hypothalamic misinformation" occurs. Hypothalamus, essential in regulation of the organism's homeostasis, becomes less sensitive to the incoming signals and this results in inadequate perception of the signals. For this reason search for hormonal preparations which would normalize the data perception in the hypothalamus is an important line of research.

Inhibitors of Protein Biosynthesis and of Energy Transformation Processes

A vast majority of researchers link the primary ageing mechanisms to molecular-biological changes in the genome. However, until very recently attempts to extend life by modifying functional characteristics of the genome were scarce. This modification is made possible by inhibitors of transcription and translation.

Inhibitors are substances which retard or nearly stop the synthesis of RNA and enzymes thus reducing the metabolism. The studies of the effect of inhibitors on the life span started with drosophila flies. Addition of optimal concentrations of transcription inhibitors into the nutrient medium of drosophilae reduced the rate of RNA and protein synthesis and increased the longevity by 20 to 30 per cent. Optimal amounts of translation and energy transformation inhibitors had approximately the same effect. In all cases suboptimal amounts had no effect and larger-than-optimal amounts drastically reduced the longevity.

First such experiments with mammals were staged in the physiology laboratory of the Gerontology Institute. Repeated injections of olivomicin, a transcription inhibitor, into the organisms of 600-days-old rats increased their average longevity to 35.6 months compared to 30.9 months in control animals, the maxima being 47.1 and 38.3 months, respectively. In the experimental animals the age-induced reduction of oxygen consumption was retarded, the erythrocytes became less stable to hemolysis, and the lipid exchange was disturbed. Olivomicin was found to reduce the content of basal lipid and cholesterol in blood serum, myocardium, brain, liver, and especially in the muscles. The concentration of unetherified fat acids decreased in all tissues other than liver. In experimental modeling of atherosclerosis olivo-

micin also had a positive impact. Biochemical and morphological analyses revealed that the preparation significantly slowed the RNA and protein synthesis in the cerebral cortex, hypothalamus, liver, and especially in the muscles whereas in the pituitary and the myocardium the rate of biosynthetic processes increased.

Temperature

Evidently the most hopeful way to increase the longevity is to reduce the body temperature. Easily modeled only for animals whose temperature is not internally thermostated, such as hibernating animals and those whose thermal regulation is primitive, e.g., the echydna and platypus, this technique may increase the longevity by a factor of tens. Thus, drosophilae flies whose incubation temperature was lowered from 35 to 15°C lived 50 times (sic) longer on the average. In the range of optimal temperatures the longevity was obviously inversely dependent on the rate of RNA and protein synthesis and oxygen and food consumption.

This effect has been found similar, qualitatively and, in most cases, quantitatively, in multicelullar organisms and the culture of cells of various origins, including human cells. These results suggest that the temperature reduction acts through basal subcellular structures which are identical in all species.

One of the possible explanations of this effect is that because of the high activation energy the rate of damaging processes (chiefly stochastic chemical processes) is reduced more than that of the vitauct processes (chiefly enzymatic). In other words, as the body temperature reduces, the ratio of vitauct and damaging processes increases in favor of the former, which may result in increased longevity.

Unfortunately, reducing the temperature of warm-blooded animals proved to be a difficult task. Thus far their temperature cannot stay reduced for more than several days. But according to computation, a reduction of two to three degrees can double the longevity of mammals, and a reduction by 10°C, increases it 15-fold. Consequently, the search for ways which would directly influence the temperature regulating centers in the hypothalamus or other elements of the thermal control system so as to obtain extensive temperature reduction seems to be a most promising way to increase the longevity of warm-blooded animals.

Genetic Factors

The existence of species of the same class whose life spans differ by a factor of tens or even hundreds speaks for the utmost importance of genetic factors. Genetics, notably genetic engineering, may offer immense possibilities of increasing the life span but now only one genetic phenomenon is known which leads to a longer life. This is heterosis, or the increased viability and fertility of the first generation of hybrid animals.

All attempts to obtain long-living strains of animals by genetic modifications have been futile. During the millenia of evolution all possible traits that favor the longest possible life have probably been found and so reduced the probability that new such traits will ever be obtained. Most mutations involving the metabolic and regulation processes in cells or in larger subsystems of the organism have decreased the longevity, in most cases by a large margin. The probability of deriving a high-longevity strain is so low that even purposeful selection proved futile [5].

Nevertheless, an increasing amount of evidence suggests

that at least many species have improved their longevity in the course of evolution. R. Cutler has demonstrated that 59 species of ungulates and 32 species of carnivores have significantly increased their longevity, especially since the Paleogene before which the life span of carnivores averaged nine years. During the Paleogene it was 14 years, during the Neogene, 17 years, and after the Neogene, 21 years; the corresponding values for ungulate species were 10, 15, 21 and 30 years.

A similar increase has been found in primates other than Hominidae for whom the increase was much larger. Thus, the maximal potential longevity of man has increased, according to comparative physiological data, by 14 years over the last 100,000 years.

* * *

Serious discussions in many countries of ways to extend the longevity and attempts to develop scientifically sound life-extending techniques for man and vegetative and animal objects mark a new important stage in biology as a whole as well as in gerontology. Because this subject is very complicated and there are numerous theoretical and experimental differences, it is very difficult to assess all possible lines of research and consequences of possible solutions to this problem. Some theoreticians illegitimately extend the results to objects of other levels of biological organization, and neglect the importance of dosage, concentration, and duration of using the life-extending factors. Hence, the predictions for the future range from unjustified rosy optimism to equally unjustified murky pessimism.

The research in this important field has encountered and will encounter difficulties, unexpected problems, successes, and disappointments. What is certain is that the organism

becomes older as a complex biological self-regulating system. The ageing processes are triggered and develop through numerous parallel and largely autonomous communication channels which make the system highly reliable.

The ageing of cells entails an increasing amount of change in the mechanisms of storage, transmission and execution of genetic information. In an organism as an entity the disorders in the neurohormonal systems which receive, analyze, and transmit regulation signals become especially important. This is seen in reduced ability to perceive and transmit information in the brain, vegetative ganglia, peripheral systems, and in feedback loops. For this reason the attempts to increase longevity by offsetting the action of some damaging factors which amount to a "disturbing signal" in one or several communication channels do not result in increasing the characteristic longevity of a species to any significant degree. More significant and stable results are obtained by using comprehensive factors such as the diet or temperature.

What is also important is that the ageing has been regarded as progressive damaging and weakening of the organism's viability. But biological objects are essentially not "one way" systems. Indeed, every cell possesses a mechanism, perfect in many respects, whereby nearly all kinds of damage are restorable. It is also capable of supercompensation. The vitauct process which has been improving during the evolution, counters the reduction of viability and acts to increase the longevity. What it does is not simply restoration of the initial stage but creation of a new kind of adaptation mechanism.

Life duration is determined by the interaction of two processes: the destructive ageing, and the counteracting process of vitauct.

Extrapolation of the experimental findings on life extension to man is an important and delicate matter. First of

all, the "price" for life extension should be assessed. For this reason the effect of life extenders on the biological age and functional integrity as well as on the longevity is being tenaciously studied. Numerous interactive indicators have been found which will make it possible to forecast the longevity.

Furthermore, the life extending factors are ineffective unless applied for a sizable part of the subject's life. In rats whose life span is short this amounts to tens of months but in man it may take years and years for these factors to have an impact, and the possible side effects are unpredictable.

In the Soviet Union the world's first comprehensive research project "Life Extension" is underway in which tens of institutes and scientists from numerous scientific disciplines such as medicine, biology, demography, chemistry, physics, etc., join their efforts to unravel the basic ageing mechanisms and to develop life-extending tools. In the framework of this project experiments with enterosorption, protein biosynthesis inhibitors, mild stresses, etc. have been carried out.

The consequences of longer life have recently become a point of contention. Some argue that the population tends to get older even without increasing the longevity. But the experimental findings of our team and by other researchers suggest that life extension puts off the disorders and pathologies of the old age and so extends the active period in human life. This effect will be beneficial for society.

References

1. Фролькис В. В. Еще раз об адаптационно-регуляторных механизмах старения.— В кн.: Геронтология и гериатрия. Киев: Институт геронтологии АМН СССР, 1979.

2. For discussion of the effect of physical and chemical factors, see: Фролькис В. В., Мурадян К. Х. Продление жизни в эксперименте.— В кн.: Физиологические механизмы старения. Л.: Наука, 1982.
3. Аршавский И. А. Механизмы, определяющие продолжительность жизни крыс, развивающихся в условиях ограниченного калоража в свете негэнтропийной теории онтогенеза.— В кн.: Геронтология и гериатрия. Киев: Институт геронтологии АМН СССР, 1979.
4. Никитин В. Н. Биохимизм и эндокринная ситуация организма лабораторных животных при экспериментальном продлении жизни сдерживающим питанием.— В кн.: Геронтология и гериатрия. Киев: Институт геронтологии АМН СССР, 1979.
5. Lints F. A., Stoll J., Grawez G., Lints C. V. An attempt to select for increased longevity in Drosophila melanogaster. Gerontology, 1979, Vol. 25.

Overhaul of Man

V. D. PEKELIS

We are proud rulers of nature. The power of our intelligence and the successes scored by science are such that we can rule to a significant degree the human organism, influence its operation and replace some of its parts.

Until very recently spare organs, similar to spare parts of various machinery, were utterly unthinkable.

In cooperation with other scientific disciplines medicine has worked numerous technological miracles:

—artificial teeth;
—joints made of metal, plastics, resins, and nylon;
—artificial spinal columns;
—lower jaws made of silastic;
—synthetic hips;
—muscles made of elastic plastic fibers;

—scull shape-correcting prosthetic plates;
—tantalum and nylon nets serving as internal prosthetic parts of the abdomenal cavity;
—prosthetic esophaguses and tracheas;
—blood vessels woven or knit of biologically inert plastic materials;
—artificial mitral valves;
—electrical pacemakers of multiyear service time, adapting to the physiological load;
—synthetic skin, permeable for water and gases and compatible with live tissues;
—glues for damaged organs and tissues;
—a bioelectrically controlled hand and microelectronically controlled limbs;
—a portable artificial kidney;
—an artificial pancreas;
—an artificial liver;
—alloplastic cornea;
—an acrylate lens.

Several models of a "vision prosthesis", an artificial eye, have been developed.

An electronic ear hears three quarters of what the natural ear does.

Artificial vocal cords can be implanted surgically.

Artificial blood is now in existence.

Engineers, not miracle workers, have developed artificial lungs.

When the human heart aches, is tired, or wants repairing, it is disconnected; the blood, in this event, is pumped by an artificial heart which stays outside the organism.

Still, medical researchers are not satisfied. They succeeded in developing a mini-heart which has operated for as long as weeks inside a human organism.

An "atomic" heart has been developed which is powered by a compact radio-isotope source which converts heat into mechanical energy.

A recent sensation was a mechanical heart of metal and plastics, powered by compressed air from an external source. Implanted in Barney Clark, a 61-year-old American, it beat for 111 days, seven hours, and 53 minutes, and made 12,912,400 beats at a rate of about 100,000 every day.

This world-famous experiment marked the start of earnest efforts to develop and test a device which would reliably operate for a long time and be capable of acting as a real heart.

What may seem quite fantastic, an electronic prosthesis of human short-term memory to control simple but vital behavior programs, is now a feasible proposition as are electronic "nervous prostheses" facilitating the functioning of some organs which are perturbed when the spinal cord is damaged. Polymers, compatible with human tissue, not interfering with the metabolic processes will in time replace damaged tissues.

Some prostheses of the future, perhaps biochemical, will have no analogs in nature. Hormone and enzyme concentrates will be injected from small capsules into the organism by an electronically controlled pump. Such units will replace faulty endocrinal glands.

The conventional ambulance service will probably be supplemented by a repair service where the surgeon's dream of replacing any faulty organ will come true. Indeed, by 1974 about 200,000 pacemakers and an unknown number of other artificial devices have been implanted.

It is believed that by the end of this century every organ other than the brain and central nervous system will be replaceable by artificial devices.

One outstanding surgeon has said that when the archeologists dig up the material remains of our culture, say 200 years later, they will find a hip joint of stainless steel, a teflon mitral valve, a synthetic polyester aorta, and an acrylate lens.

Some medical researchers and biologists go as far as visualizing a "bionic man" most of whose systems will consist of artificial human-like elements.

Another trend in man's overhaul is using donor organs.

V.P. Demikhov, an authority in pathophysiology, believes that today every irreversibly damaged organ can be replaced by a donor organ and this is a major life preserving technique.

Our life span is limited. Timely and skillful "maintenance", medium repair or "overhaul" will extend the patient's life.

In the same organism different parts may be "of different physiological age". The heart and liver of a 40-year-old may be of a 50-year-old individual, the muscles 30, and the brain 99. A thorough clinical study of an apparently healthy 17-year-old girl revealed that her heart was like that of a woman of 50 and brain, like that of a woman of 75.

At the World Congress of Surgeons in Vienna in 1967 two patients with pancreas transplants were demonstrated. Cases of successful transplantation of donor lungs and livers were discussed. Kidney transplants had ceased to be a sensation. Some surgeons have performed scores of such operations. Some patients have been living for years with implanted kidneys. Parts of the heart such as the mitral valve taken from a pig or sheep have been implanted in quite a few patients.

By 1971 over 5,000 liver, over 100,000 lung, over 30 pancreas and one heart-and-lung transplant surgeries had been performed in the world. By 1975 19,000 kidneys had been

implanted. Nine thousand such patients are alive. One of them has a kidney implanted nearly 20 years ago.

Transplantations are performed now on a mass scale. Back in 1974 surgeons predicted that by 1980 about a million donor pancreases would be needed in the USA alone.

It was a world sensation when the first heart transplant operation was performed on December 3, 1967. A man of 50 received a young strong heart of a woman of 20. A donor heart beat in him for days. He died but this surgery demonstrated that an "overhaul" was a realistic proposition. Other heart transplant operations followed. By the end of 1968 86 such surgeries had been performed. On two patients the surgery was repeated. In one man even the second transplant heart had to be replaced. The man who had four hearts in his life, including his own one, may be still alive.

A 14-year-old boy had a donor heart which supplemented his own, which was very weak. When it stopped beating, his own heart was removed and another donor heart implanted. So, he had two (sic) donor hearts beating side by side.

Philip Bliberg, the famous patient of Professor Christian Barnard, lived 19 months and a half, or 584 days, with a donor heart.

According to foreign press, by 1971 forty people had lived with donor hearts for more than a year and six people for more than two years. Louis Russel, 43, and Charles P. Johnson, 61, who lived with donor hearts for more than six years were known as the miracles of the 20th century. Betty Anique, 50, was alive with somebody else's heart for almost eight years and a half. In April 1980 Dorothy Fisher of Capetown celebrated the eleventh anniversary of the surgery. William Beuren, an American, was 50 in

1970 when he received a donor heart. In April 1983 he was reported alive and in good shape. "The eldest" of all such patients as of November 27, 1982, was Emmanuel Vitria, a Frenchman, whose heart was replaced in November 1968.

Of course the reader has noted that I use the past tense. It is because I do not know what happened to these people since then.

James Greenal who lives with a donor heart is 32. He had a healthy child 16 months after the surgery. He works and lives like anybody else.

By 1974 two hundred and nineteen heart transplants operations had been performed. By that time 36 of these patients remained alive. By 1975 two hundred and seventy one such surgeries had been performed; 47 patients were alive, of whom 14 for more than three years and eight for at least five years.

Within ten years, from 1967 to 1977, over 300 heart transplant operations were performed, 63 patients, or every fifth patient, were alive. The post-surgery longevity averaged 300 days.

According to Professor Christian Barnard, the pioneer of such surgeries, the probability of living one year after the transplantation was seven per cent; of living two years, five per cent; and of living five years, more than three per cent.

Fifteen years after this prediction was made, 42 per cent of those operated for heart transplantation lived for more than five years in 1982.

Tens and hundreds of people who would have been doomed a few years ago are now alive thanks to transplantation.

The man of Phoenix who had himself frozen to be resusciated in the 21st or 22nd century failed simply because he

died. However, Sazio Suida, a Japanese physician, succeeded in bringing back to life several animal hearts that had been kept frozen for two years. Some people were rescued after deep freezing. Vegard Slettemuen, a five-year-old Norwegian boy, was revived after an hour of clinical death. Vladimir Khorin, a Soviet tractor driver of 24, who had been frozen in the steppe, was clinically dead for hours before doctors pulled him back to life. This is a record-breaking event in itself.

Now biologists, chemists, and physicists study the thermoregulatory mechanisms in hibernating animals in order to find such ways of cooling that living organisms could be brought back to normal functioning.

The hibernation-initiating substance, which was isolated in animals, will make it possible to store transplant organs for a long time. New ways of freezing live cells (a subject of research in the entire world) make it possible to store plant seeds, skin tissues, cornea, and embryos.

Attempts are made to use vitrification, i.e., transformation of a liquid first into a viscous and then glass-like state, so as to avoid crystallization which destroys living tissues. If this research succeeds, live tissues could be frozen for long-term storage.

Even so, the potential of our organism is not infinite and it is improbable that life functions could be restored, or "resuscitation from the dead" can be achieved after decades of freezing.

It is hard to say now whether donor organs or artificial organs will be preferred for man's "overhaul".

Because "spare parts" should be available for transplantation, in particular for heart transplantations, surgeons call for setting up "banks of human organs". Some inter-city and international banks of this kind exist now. But if the rate of transplantation increases, which seems to be the case,

no storage "banks" will cope with the demand. Therefore, artificial "spares" will probably be preferred. Breakthroughs are quite possible very soon. Miniaturization and high sensitivity and reliability of new devices (the weight of heart pacemakers has dropped from 275 to 75 g within 15 years) will most probably result in harmless, easily implantable spares, ranging from vision and auditory prostheses to artificial hearts and lungs capable of operating for quite a long time.

Still another possibility is offered by "live prostheses".

Theoretically, nothing prevents us from learning in time to grow a new limb (as in experimentation with frogs). Regeneration is known in man, too. The hair, nails, skin, and even the muscles, cornea, and liver cells are either regenerated or grow anew. Reptiles such as salamanders and tritons are capable of regenerating parts of eyes and other organs, notably the heart, as well as the extremities and tail. Biological methods have been developed which restore the regenerating ability in some organs and tissues such as injured scull bones in mammals and man. New bone tissue is formed by the organism in this case by some, thus far unknown, mechanism.

By stimulating the regeneration the healing of injuries in the heart muscle may be accelerated. Experiments are underway with tissue transplantation into the patient's brain. Cells of the patient's own adrenal gland were transplanted in order to replenish the store of the brain matter.

Professor L.V. Polezhaev, a widely known expert in organ regeneration, agrees that the very idea of growing a new leg or arm may seem fantastic now but says that research and experimentation may make this dream come true in a not-too-distant future.

If scientists succeed in determining how the cells are

differentiated and how they connect into tissues, these processes will be carried out in the tissue culture. When a child is born early in the 21st century, a fraction of the placenta will be placed frozen on cold storage. Whenever the individual needs a new heart or kidney, the necessary organ will be grown from the placenta cells and then implanted. There will be no need in donors, and biological compatibility will cease to be a problem.

About the Authors

Igor M. MAKAROV, Corresponding Member of the USSR Academy of Sciences, Chairman of the Scientific Board on Robotics under the USSR Academy of Sciences.

Academician Yuri A. OVCHINNIKOV, Vice-President of the USSR Academy of Sciences, Director of the M.M. Shemyakin Institute of Bioorganic Chemistry.

Professor Nikolai V. TIMOFEEV-RESOVSKY (1900-1981), D.Sc. (Biol.), scientific advisor at the Institute of Medico-Biological Sciences of the USSR Ministry of Public Health.

Academician Aleksandr A. BAEV, Academician-Secretary to the Department of Biochemistry, Biophysics, and Chemistry of Physiologically Active Compounds at the USSR Academy of Sciences.

Genrikh R. IVANITSKY, Corresponding Member of the USSR Academy of Sciences, Director of the Scientific Center for Biological Research of the USSR Academy of Sciences in Pushchino and of the Institute of Biological Physics, USSR Academy of Sciences.

Professor Valentin I. KRINSKY, D.Sc. (Phys.-Math.), Director of the Laboratory of Autowave Excitation Processes at the Institute of Biological Physics, USSR Academy of Sciences.

Oleg A. MORNEV, junior researcher in the Laboratory of Autowave Excitation Processes at the Institute of Biological Physics, USSR Academy of Sciences.

Aleksei A. LYAPUNOV (1911-1973), Corresponding Member of the USSR Academy of Sciences, carried out research in control theory, in particular, in cybernetic aspects of biology.

Mikhail V. VOLKENSHTEIN, Corresponding Member of the USSR Academy of Sciences, Director of the Laboratory of Biopolymer Physics at the Institute of Molecular Biology, USSR Academy of Sciences; Director of the Department for Physics for Biomolecular Structures at the Institute of Biological Physics, USSR Academy of Sciences.

Professor Yuri M. SVIREZHEV, D.Sc. (Phys.-Math.), Director of the Laboratory of Mathematical Biology, the USSR Academy of Sciences Computing Center.

Academician Viktor G. AFANASYEV, philosopher, Editor-in-Chief of *Pravda*.

Professor Boris V. BIRYUKOV, D.Sc. (Philosophy), senior researcher in the Scientific Council on the Comprehensive Program "Cybernetics" under the Presidium of the USSR Academy of Sciences.

Boris F. LOMOV, Corresponding Member of the USSR Academy of Sciences, Corresponding Member of the USSR Academy of Pedagogical Sciences, Director of the Psychology Institute, USSR Academy of Sciences.

Academician Pyotr K. ANOKHIN (1898-1974), a specialist in the brain physiology, the author of the theory of functional systems.

Professor Aleksandr B. KOGAN, D. Sc. (Biol.), Director of the Institute of Neurocybernetics of the North-Caucasian Scientific Center.

Valery N. REUSHKIN, Cand. Sci. (Med.).

Vadim S. ROTENBERG, D. Sc. (Med.), senior researcher of the Psychophysiology and Psychodiagnostics Department, 1st Moscow Medical Institute.

Valentina I. KLIMOVA, member of the USSR Journalists

Union, member of the *Kaleidoskop tekhniki* editorial board.

Academician Arkady B. MIGDAL, theoretical physicist, Head of Department at the L.D. Landau Institute of Theoretical Physics, USSR Academy of Sciences.

Yelena V. NETYOSOVA, historian, researcher in science methodology.

Professor Simon E. SHNOL, D. Sc. (Biol.), Director of Laboratory for Physical Biochemistry at the Institute of Biological Physics, USSR Academy of Sciences, Professor of the Biophysics Department of the Physics Faculty of Moscow University.

Professor David I. DUBROVSKY, D. Sc. (Philosophy), Philosophy Faculty of Moscow University, member of the editorial board and head of the department of dialectic materialism, logic, and philosophical problems in natural sciences of *Filosofskie nauki* journal.

Academician Yuri V. GULYAEV, Deputy Director of the Institute of Radio Engineering and Electronics, USSR Academy of Sciences.

Eduard E. GODIK, D. Sc. (Phys.-Math.), Director of Laboratory for Biomedical Radioelectronics at the Institute of Radio Engineering and Electronics, USSR Academy of Sciences.

Viktor L. VVEDENSKY, Cand. Sci. (Phys.-Math.), researcher in the Laboratory of Physical Properties of Materials at the I.V. Kurchatov Institute of Atomic Energy.

Professor Valery I. OZHOGIN, D. Sc. (Phys.-Math.), Head of the Laboratory of Physical Properties of Materials at the I.V. Kurchatov Institute of Atomic Energy, Professor of the Solid State Physics Department at the Moscow Institute of Radio Engineering, Electronics, and Automation.

Vsevolod S. TROITSKY, radio physicist and radio astronomer, Corresponding Member of the USSR Academy of Sciences, Director of Department at the Radio Engineer-

ing Research Institute of the RSFSR Ministry of Public Health and the USSR Academy of Sciences (Gorky), member of the International Astronomical Union and the International Telecommunications Union.

Boris M. VELICHKOVSKY, Cand. Sci. (Psychology), Assistant Professor of the General Psychology Department of Moscow University, experimental psychologist, specializes in psychology of cognitive processes.

Pavel V. SIMONOV, Corresponding Member of the USSR Academy of Sciences, Director of the Institute of Higher Nervous Activity and Neurophysiology, USSR Academy of Sciences.

Vladimir F. FROLKIS, Corresponding Member of the Ukrainian Academy of Sciences, Head of the Experimental Department at the Gerontology Institute of the USSR Academy of Medical Sciences.

Khachik K. MURADYAN, Cand. Sci. (Biol.), senior researcher in the Physiology Laboratory at the Gerontology Institute of the USSR Academy of Medical Sciences.

Viktor D. PEKELIS, an essayist, member of the USSR Writers Union.

TO THE READER

Mir Publishers welcome your comments on the content, translation, and design of the book.

We would also be pleased to receive any suggestions you care to make about our future publications.

Our address is:
USSR, 129820,
Moscow, I-110, GSP, Pervy
Rizhsky Pereulok, 2,
Mir Publishers

OTHER BOOKS FOR YOUR LIBRARY

Cybernetics Today:
Achievements, Challenges, Prospects
Edited by I. Makarov,
Corr. Mem. USSR Acad. Sc.

Approaching the subject from various points of view, the contributors to this book examine the key problems of cybernetics, both theoretical and applied. In doing so, they draw upon a wide range of disciplines related to cybernetics in one way or another. Ample space is devoted to the economic aspects of informational technology, man-machine systems and interactions, and the prospects of cybernetics in the future, notably the creation of artificial intellect novel for computers, and advanced robots. All this—and more—comes as first-hand information from men in the forefront of present-day science.

Contents. From Discussions of Different Years. The State of the Art. Artificial Intelligence: Pros and Cons. On Some Control Problems. The Fine Arts and Cybernetics. From a New Angle. Foreseeing the Future.

Cybernetic Medley
V. Pekelis

This book, by the well-known Soviet science writer, Victor Pekelis, is basically an introduction to cybernetics, the science that has to do with a comparative study of up-to-date electronic computers and the human nervous system. The book deals with origins, development, state-of-the-art, actual potentialities and foreseeable bounds of application. Much space has been allotted to the immence contributions of cybernetics to modern science and engineering.

Contents. Thirty Years Later. Strolling Through Exhibitions. Man/Machine Dialog. Are Leaves and Soil in Need of Formulae? Automation of Automata. The Last Episode from the Life of Robots. Crime and Punishment. Experience with Telepathy. Machines at the Chess-board. Leonardo da Vinci of the 21st Century. Information Explosion. Is Cybernetics Used in Sports? Old Age and Cybernetics. The Machine as a Teacher. Dredges of Science. Will Cybernetics Kill Invention? A Horse Named Charley. Machines and Foresight. War and Cybernetics. Wiener and America.

This Chancy, Chancy, Chancy World
L. Rastrigin, D. Sc. (Phys.-Math.)

A book for young readers on the role and meaning of chance, accident, the fortuitous, and stochastic processes in life and science.

In this first effort at popularization Prof. Rastrigin raises, and hazards answers to many problems. Why is there chaos? Why is control needed? What happens in a random situation? How can we get around the inconveniences arising from accidental interference in our lives? What is the Monte Carlo method? Why is training necessary? What is the role of chance in evolution and progress?

Contents. Part. I. Chance the Obstacle. Chance at the Cradle of Cybernetics. Control. The History of Control. The Battle with Chance Interference. Alternatives, Risk and Decision. Part II. Welcome Chance. Sherlock Holmes Speaks His Mind at Last. The Monte Carlo Method. Chance in Games. Learning, Conditioned Reflexes, and Chance. Chance and Recognition. Chance, Selection, and Evolution. Self-adjustment. Search (Paths and Wanderings).

The book has been written by a team of leading Soviet authorities in the field of cybernetics, among them Academicians Yu. Ovchinnikov, A. Baev, V. Afanasyev, P. Anokhin, A. Migdal, Yu. Gulyaev.

The contributors discuss the latest achievements in biology from the viewpoint of cybernetics, describe multiple functions that constitute living matter, the basis of brain reliability, the psychics modeling limits, and the mathematical methods in psychology. Also, they examine the problems relating to life and age, death and immortality, and the experimental ways of making life longer.

The book will undoubtly be of interest to all those interested in, or concerned with, cybernetics or allied fields.